Faculty of Health Sciences

The “deep caries” challenge

Prevalence and management of deep carious lesions in Northern Norway

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This thesis is dedicated to the friend of my life, Mathieu, and my other two little fellows, who always share their good energy with me.

“When meditating over a disease, I never think of finding a remedy for it, but, instead, a means of preventing it.”

Louis Pasteur, French scientist (1822-1895)
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LIST OF ABBREVIATIONS

CH, calcium hydroxide
CI, confidence interval
DCL-CC, deep carious lesions and other consequences of caries
DMFT, decayed, missing and filled teeth
DPC, direct pulp capping
GDPs, general dental practitioners
IPC, indirect pulp capping
MTA, mineral trioxide aggregate
OR, odds ratio
PRR, prevalence rate ratio
PDHS, public dental health service
PP, partial pulpotomy
RCT, randomized clinical trial
SWE, stepwise excavation
TCE, total caries excavation
VPT, vital pulp therapy
LIST OF ORIGINAL ARTICLES

This thesis consists of three papers, referred to in the text by the corresponding roman numerals.

I. Deep carious lesions and other consequences of caries among 18-year-olds at Public Dental Health Service in Northern Norway: a cross-sectional age cohort study

Stangvaltaite L, Kundzina R, Bolstad NL, Eriksen HM, Kerosuo E.

*Acta Odontologica Scandinavica*, 2014 [Epub ahead of print print].

II. Treatment preferences of deep carious lesions in mature teeth: questionnaire study among dentists in Northern Norway

Stangvaltaite L, Kundzina R, Eriksen HM, Kerosuo E.


**Capping carious exposures in adults: a RCT comparing calcium hydroxide and MTA**

Kundzina R, Stangvaltaite L, Eriksen HM, Kerosuo E.

In manuscript.
1. ABSTRACT

The overall aim of this doctoral thesis was to increase the understanding and knowledge of the prevalence and management of deep carious lesions. The prevalence of dental caries in Norway was among the highest in the world in the middle of 20th century. Though it has significantly declined, there are indications that the prevalence of caries in Northern Norway is higher than in the rest of the country. A higher prevalence of caries might lead to a higher prevalence of deep carious lesions. **Study I** focused on the prevalence of deep carious lesions and other consequences of caries (DCL-CC) among 18-year-olds enrolled in the Public Dental Health Service in Northern Norway. There were 488 (26%) subjects having at least one molar with DCL-CC. The mean decayed, missing, and filled teeth (DMFT) (SD) score among these 488 subjects was 9.1 (4.6), twice as high as among subjects without DCL-CC (4.5, SD 4.0). The most prevalent modality among untreated deep carious lesions, deep restorations, root canal obturated molars, and molars extracted due to caries were deep restorations, which were observed among 21.5% (n=404) of the age cohort. Root canal obturated molars, molars extracted due to caries, and untreated deep carious lesions were prevalent in 5.1%, 3.6% and 1.6% of this age cohort, respectively. The high prevalence of DCL-CC in Northern Norway is of concern and presents a challenge for dentists, as no treatment guidelines exist for deep carious lesions. **Study II** was a questionnaire study that investigated the preferred treatment methods of general dental practitioners in Northern Norway for deep carious lesions and carious exposures in mature permanent teeth. **Study II** underlined the lack of uniformity in preferred treatment methods among the respondents, and the inconsistency of these methods with those suggested in the current literature. For example, in the absence of symptoms, total caries excavation was favored by a majority of respondents (49%), while in presence of symptoms (indicating reversible pulpitis at most), pulpectomy followed by endodontic treatment was the preferred treatment method for 39% of respondents. Direct pulp capping (DPC), mainly with
calcium hydroxide (CH), was the most preferred treatment method (51%) for carious exposures in the absence of symptoms, although it is still a controversial treatment method for adults. In Study III, a promising capping material, mineral trioxide aggregate (MTA), was tested against the gold standard material CH for DPC on carious exposures in adults. After 2-3 years of follow-up, the estimated cumulative survival rate for molars capped with MTA was statistically significantly higher (80%) than for molars capped with CH (46%) (p=0.018). The study is still ongoing, but there are indications that it may provide evidence that will change the established recommendations for the treatment of carious exposures in adults.
2. INTRODUCTION

2.1. Definition of deep carious lesion

Dental caries is one of the most important global oral health burdens and is the most common childhood disease worldwide. It is also the most prevalent oral disease in several Asian and Latin American countries and has a significant impact on quality of life and public health (Petersen, 2003; Beaglehole et al., 2009). Caries is a progressive disease that causes demineralization and destruction of the hard tissues of the teeth. It starts in the enamel as a white spot lesion. If it is not managed, cavitation will develop and will progress into the dentine. Deep carious lesion is a clinical diagnosis that is given when the carious process has penetrated deep into the dentine with possible pulpal exposure (Nygaard-Østby, 1951). Deep carious lesions cause pulpal inflammation (i.e., pulpitis); if not managed, they may result in pulp necrosis and involvement of the periradicular tissues, with possible pain requiring endodontic treatment or extraction (Torneck, 1974; Langeland, 1987).

Deep carious lesions can be detected clinically and/or radiographically. Clinically, according to the contemporary International Caries Detection and Assessment System (ICDAS) the most severe carious lesion is called “extensive” and is indicated by code 6 (on a scale from 1 to 6) (Pitts, 2004). An extensive carious lesion is both deep and wide, with visible dentine on the cavity walls and at the base; the carious process histologically involves at least half of the tooth surface or may reach the pulp (Ismail et al., 2007). The carious lesion is classified as “active” when it has a yellowish color and a soft, moist consistency. A carious lesion is classified as “inactive” (arrested) when it is heavily pigmented, hard, leathery, and dry (Miller and Massler, 1962; Sarnat and Massler, 1965). Carious dentine consists of two layers: the outer layer, which has been infected by bacteria, has disintegrated, and is not able to remineralize due to the destruction of collagen, and the inner layer, which, although affected by
acids from bacteria (but not by bacteria itself) is able to remineralize, as the collagen texture is still intact (Fusayama, 1979; Fusayama and Terachima, 1972).

Radiographically, deep carious lesions are defined as those close to, but not into the pulp (King et al., 1965). There is no unanimous agreement about the depth that qualifies “a deep carious lesion”. Instead, a carious lesion is considered deep when pulpal exposure is anticipated during total caries excavation (Fitzgerald and Heys, 1991; Bjørndal et al., 1997). However, this has been shown to be subjective measurement, as radiographic depth might vary from half into the dentine to reaching the pulp (Bjørndal and Thylstrup, 1998). Radiographically, carious lesions penetrating halfway or more into the dentine (Maltz et al., 2013), into the inner third of the dentine (Ekstrand et al., 1997; Maltz et al., 2011), or into the inner fourth of the dentine have also been assessed as deep (Massler and Pawlak, 1977; Bjørndal, 2010).

2.2. Prevalence of caries in Norway

The prevalence of caries has declined in a majority of industrialized countries during the last decades (Marthaler, 2004). This marked improvement has been extensively documented, particularly among children and adolescents (Marthaler et al., 1996; Petersson and Bratthall, 1996). The prevalence of caries in Nordic countries was among the highest in the world in the 1970s and 1980s, when the DMFT score among 18-year-olds in Norway was 18.4 compared to 4.6 in Hong Kong and the USA and 6.3 in Malaysia (FDI et WHO, 1985). During recent years, the DMFT score among 12-year-olds and 18-year-olds in Norway has declined significantly; in 2011 these scores were 1.1 and 4.3, respectively (von der Fehr, 1982; Haugejorden, 1994; Birkeland et al., 2002; Statistics Norway, 2012)(Fig. 1).

All children in Norway receive free, systematic dental care within the framework of the Norwegian Public Dental Health Service (PDHS) until 18 years of age. Despite this fact, not all children benefit equally from the PDHS. In 1991, 92% of 12-year-olds received treatment through the PDHS, but only 81% of 18-year-olds attended (Norwegian Board of Health, 1992).
The mean individual frequency of cancelled and missed dental appointments among 18-year-olds in 1996 was 4.8% and 11.8%, respectively, and these individuals had a statistically significantly higher mean DMFT score than their peers who did attend their appointments (Skaret et al., 1998).

Figure 1. DMFT scores among 12-year-olds and 18-year-olds in Norway, 1971-2011.


A similar prevalence of caries was observed in Northern Norway compared to the rest of the country in the late 1970s, but the prevalence of untreated carious lesions was higher in Northern Norway (Heløe et al., 1980). A study performed 2 decades ago reported a mean number of untreated carious lesions reaching the inner half of the dentine in proximal surfaces of 0.11 and 0.02 in Northern and Southern Norway, respectively (Wang and Riordan, 1995). In Northern Norway about one in every five 18-year-olds have a DMFT score higher than 9, which is twice as high as that in Southern Norway (Statistics Norway, 2012). High DMFT score and untreated carious lesions are the main risk factors for deep carious lesions and pulpal involvement, which result in deep restorations, root canal obturations, and extractions (Benzian
et al., 2011; Siqueira Jr., 2012). In 1966, the mean number of permanent teeth extracted due to caries per 100 patients among 6-17-year-olds in Northern Norway was 12 compared to 3 in Southern Norway (von der Fehr and Haugejorden, 1997); however recent data regarding the prevalence of deep carious lesions and other consequences of caries, such as deep restorations, root canal obturations, and extractions, among 18-year-olds in Northern Norway is not available.

2.3. Pulpal status in relation to deep carious lesions

Pulpal status in deep carious lesions varies from almost normal to severe, acute, or chronic pulpitis terminating in necrosis (Massler, 1967; Massler and Pawlak, 1977). The degree of inflammation in the pulp increases with the depth of the carious lesion (Massler and Pawlak, 1977). When a carious lesion approaches within 0.5mm of the pulpal wall of dentine, the amount of pulpal pathosis begins to increase, when the carious process reaches the tertiary dentine, there are irreversible changes that occur in the pulp, such as abscess formation, and a large amount of granulation tissue can be detected (Reeves and Stanley, 1966; Murray et al., 2003). Considerable pulp inflammation has been observed with 0.3 mm of residual dentine, and bacteria in the pulp has been detected with a residual dentine thickness of 0.2 mm or less (Shovelton, 1968). Bacterial invasion in the pulp, acute inflammation with abscess formation, and pulpal necrosis was observed after natural carious exposure (Seltzer et al., 1963a; b; Massler and Pawlak, 1977; Baume and Holz, 1981).

The degree of pulpal inflammation has been shown to depend on the activity of the deep carious lesion. In arrested deep carious lesions, the pulpal status tends to be almost normal, showing sclerosis and repair. In active deep carious lesions, more severe inflammatory process is seen (Massler, 1967). However, active and arrested processes can coexist (Kidd, 2004). The healing potential of the pulp depends on the degree of inflammation and the depth and activity of deep carious lesions might be one of the most important determinants (Bjørndal et al., 2014).
The major challenge in a clinical context is to determine whether pulpitis is reversible or irreversible. Scientific evidence is insufficient to assess the accuracy of the correlation between clinical signs and symptoms of pain and the degree of pulpal inflammation (Seltzer et al., 1963a; b; Reeves and Stanley, 1966; Mejäre et al., 2012). A recent study based on different clinical and histological criteria found a 96.6% correlation between the clinical and histological signs associated with reversible pulpitis and an 84.4% correlation with irreversible pulpitis. The authors concluded that in the absence of natural carious exposure, pulpitis is usually reversible (Ricucci et al., 2014b). There is no non-invasive tool available for assessing the degree of pulpal inflammation.

Reversible pulpitis is usually diagnosed in teeth with deep carious lesions that are asymptomatic or have only short-term sharp pain upon thermal or chemical stimulation (Torabinejad and Shabahang, 2009). Irreversible pulpitis, if not asymptomatic, can present with lingering or spontaneous pain (Levin et al., 2009). In irreversible pulpitis, the pulp is vital but severely inflamed, with some possible necrosis, which makes healing an unlikely outcome (Levin et al., 2009). Symptoms of pulpitis can be very misleading, as 40%-60% of both reversible and irreversible cases may be asymptomatic (Hasler and Mitchell, 1970; Michaelson and Holland, 2002). “Painless pulpitis” is diagnosed more often among older patients (Michaelson and Holland, 2002). Necrosis of the pulp is diagnosed when vital signs and symptoms are lost (Levin et al., 2009).

2.4. Treatment options for deep carious lesions

There are three treatment options for deep carious lesions with no pain or with mild symptoms that suggest reversible pulpitis at most: i) total caries excavation (TCE); ii) stepwise excavation (SWE); and iii) indirect pulp capping (IPC) (Fig. 2, Table 1). TCE is a procedure during which all infected and affected carious dentine is removed (cited in Jordan and Suzuki, 1971). A procedure is called SWE when a layer of carious dentine is left on the pulpal floor and the
carious lesion is later re-entered in order to perform TCE (Bodecker, 1938; Bjørndal et al., 1997). IPC is a procedure when partial carious tissue excavation and permanent cavity restoration is performed in the same visit (Eidelman et al., 1965; Fitzgerald and Heys, 1991; Maltz et al., 2011; Maltz et al., 2012a).

**Figure 2. Treatment options for deep carious lesions related to diagnosis and absence/presence of pulpal exposure.**

*Pulpectomy in case of reversible and irreversible pulpitis; root canal treatment in case of necrotic pulp.

Total caries excavation

In the early 20th century, G.V. Black suggested the use of TCE (cited in Jordan and Suzuki, 1971). Advocates of TCE argued that it was necessary in order to determine “whether sufficient secondary dentine has been formed to protect the pulp or whether the carious process has
Table 1. Overview of studies on the treatment of deep carious lesions in permanent teeth.

<table>
<thead>
<tr>
<th>AUTHOR</th>
<th>DESIGN</th>
<th>NUMBER OF TEETH, AGE OF SUBJECTS</th>
<th>TREATMENT®, MATERIAL(S)</th>
<th>CONTROL, MATERIAL(S)</th>
<th>DEPTH OF LESION, PULPAL STATUS</th>
<th>FOLLOW-UP</th>
<th>MAIN OUTCOMES</th>
</tr>
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<tbody>
<tr>
<td><strong>Studies investigating SWE and SWE versus TCE</strong></td>
<td></td>
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</tr>
<tr>
<td>Jordan &amp; Suzuki, 1971</td>
<td>Prospective</td>
<td>n=243</td>
<td>SWE</td>
<td>-</td>
<td>Pulpal exposure expected*, Reversible pulpitis at most, hypersensitivity and mild pain included</td>
<td>-</td>
<td>Success rate (vital pulp, radiographic and clinic presence of remineralization, absence of exposure): 98% Radiographic signs of remineralization between 10-16 weeks (mean 12)</td>
</tr>
<tr>
<td>Leksell et al., 1996</td>
<td>RCT</td>
<td>n=57 treatment, n=70 control</td>
<td>SWE</td>
<td>TCE</td>
<td>Pulpal exposure expected*, 1-11 years (mean 3.6)</td>
<td>1-11 years</td>
<td>Pulp exposure: SWE 17.5%, TCE 40% Success rate (normal clinical and radiographic conditions): SWE 82%, TCE 60%</td>
</tr>
<tr>
<td>Bjørndal et al., 1997</td>
<td>Prospective</td>
<td>n=31, Unknown</td>
<td>SWE</td>
<td>-</td>
<td>Pulpal exposure expected*, 18 lesions &gt;1/3, 13 ≤1/3 into dentine; Reversible pulpitis at most</td>
<td>6-12 months</td>
<td>No exposures Dentine harder, darker, dryer at re-entry, reduction in colony forming units</td>
</tr>
<tr>
<td>Bjørndal &amp; Thylstrup, 1998</td>
<td>Prospective, multi center</td>
<td>n=94, 11-65 years (median 24)</td>
<td>SWE</td>
<td>-</td>
<td>1 lesion &lt;1/2, other ≥1/2 into dentine, Reversible pulpitis at most</td>
<td>1 year</td>
<td>Five exposures Dentine harder and darker at re-entry Success rate (vital pulp, absence of subjective symptoms and periapical lesion): 93%</td>
</tr>
<tr>
<td>Bjørndal &amp; Larsen, 2000</td>
<td>Prospective</td>
<td>n=9</td>
<td>SWE</td>
<td>-</td>
<td>1 lesion &lt;2/3, other ≥2/3 into dentine, Reversible pulpitis at most</td>
<td>4-6 months</td>
<td>No exposures Dentine darker, dryer at re-entry, reduction in colony forming units, dominated not cariogenic flora</td>
</tr>
<tr>
<td>Study Authors</td>
<td>Study Design</td>
<td>N</td>
<td>Material 1</td>
<td>Material 2</td>
<td>Material 3</td>
<td>Procedure</td>
<td>Duration</td>
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<tr>
<td>Bjørndal et al., 2010</td>
<td>RCT multi-center</td>
<td>n=143 treatment; n=149 control</td>
<td>≥ 18 years</td>
<td>SWE, Re-entry after 8-12 weeks CH (Dycal)</td>
<td>TCE, CH</td>
<td>≥3/4 into dentine with well-defined radiodense zone, Reversible pulpitis at most, mild-moderate pain included</td>
<td>1 year</td>
</tr>
<tr>
<td>Corralo &amp; Maltz, 2013</td>
<td>RCT</td>
<td>n=19 CH; n=19 GIC; n=19 wax, 11-35 years (mean and median 18)</td>
<td>SWE, CH (Dycal), GIC (Vitromolar)</td>
<td>SWE, wax</td>
<td>≥2/3 into dentine, Reversible pulpitis at most</td>
<td>3-4 months</td>
<td>100% vital pulps and absence of periapical lesions On re-entry dentine harder, less cariogenic bacteria, no sig. difference between materials</td>
</tr>
<tr>
<td>Fitzgerald &amp; Heys, 1991</td>
<td>Prospective Random selection of material</td>
<td>n=24 IPC CH (Life); n=26 IPC CH (Dycal); n=20 TCE CH (Life); n=23 TCE CH (Dycal); n=20 TCE ZOEiii; n=20 TCE CH (Dycal), 20-60 years (mean 27)</td>
<td>IPC, CH (Dycal, Life); TCE, CH (Dycal, Life), ZOEiii</td>
<td></td>
<td>Pulpal exposure expectediv for IPC and pulpal exposure not expected for TCE, Reversible pulpitis at most</td>
<td>12 months</td>
<td>No sig. difference in symptoms between materials and treatments Sig. decrease in symptoms from pretreatment to six months and from six months to one year in IPC</td>
</tr>
<tr>
<td>Maltz et al., 2002</td>
<td>Prospective</td>
<td>n=32, 12-23 years</td>
<td>IPC, CH (Dycal)</td>
<td>-</td>
<td>Pulpal exposure expectedv, Reversible pulpitis at most</td>
<td>6-7 months</td>
<td>1 exposure during provisional sealing removal, 1 pulpal necrosis, 31 teeth did not present clinical symptoms On re-entry 100% of lesions dry, 80% hard, 17% leathery, 3% soft, reduction in colony forming units</td>
</tr>
<tr>
<td>Gruythuysen et al., 2010</td>
<td>Retrospective</td>
<td>n=34, ≤ 18 years</td>
<td>IPC, Resin-modified glass ionomer</td>
<td>-</td>
<td>Lesion or restoration &gt;2/3 into dentine, pulp exposure expectedvi, Reversible pulpitis at most</td>
<td>3 years</td>
<td>Survival rate (normal clinical and radiographic conditions): 93%</td>
</tr>
<tr>
<td>Orhan et al., 2010</td>
<td>RCT</td>
<td>Permanent teeth: n= 19 IPC; n=17 SWE; n=24 TCE,</td>
<td>IPC, CH (Dycal); SWE</td>
<td>TCE</td>
<td>Pulpal exposure expectedvi, Reversible pulpitis at most</td>
<td>1 year</td>
<td>Pulp exposure for permanent teeth: IPC 5%, SWE 6%, TCE 25% Success rate for permanent teeth (vital not exposed pulp, absence of</td>
</tr>
</tbody>
</table>

**Studies investigating IPC, IPC versus TCE and IPC versus SWE**
<table>
<thead>
<tr>
<th>Study</th>
<th>Design</th>
<th>n</th>
<th>Age (Range)</th>
<th>Treatment</th>
<th>Entry Interval</th>
<th>Re-entry</th>
<th>Follow-up</th>
<th>Outcome Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maltz et al., 2011</td>
<td>Prospective</td>
<td>31</td>
<td>12-23 years</td>
<td>IPC, CH (Dycal)</td>
<td>-</td>
<td>≥2/3 into dentine, pulpal exposure expected&lt;sub&gt;iv&lt;/sub&gt;, reversible pulpitis at most</td>
<td>1.5 years</td>
<td>3 years 5 years 10 years</td>
</tr>
<tr>
<td>Maltz et al., 2012</td>
<td>Prospective</td>
<td>60</td>
<td>12-50 years</td>
<td>IPC, CH (Dycal)</td>
<td>TCE</td>
<td>&gt;2/3 into dentine, pulpal exposure expected&lt;sub&gt;iv&lt;/sub&gt;, reversible pulpitis at most</td>
<td>6-7 months for IPC</td>
<td></td>
</tr>
<tr>
<td>Maltz et al., 2012 RCT multi-center</td>
<td>RCT multi-center</td>
<td>112</td>
<td>6-53 years (median 14, mean 17)</td>
<td>IPC, CH (Dycal)</td>
<td>SWE</td>
<td>≥1/2 into dentine, reversible pulpitis at most</td>
<td>3 years</td>
<td></td>
</tr>
</tbody>
</table>

<sub>1</sub> Analyzed.
<sub>2</sub> In case of SWE, the interval before re-entry is indicated.
<sub>3</sub> Zinc oxide eugenol.
<sub>4</sub> In case of total caries excavation.
penetrated into the pulp” and to establish an appropriate treatment plan (Berk, 1957). The second argument was that TCE was crucial in order to determine the exact outline of the cavity and to provide a well-mineralized dentine base that would ensure a tight seal, as well as the longevity of the restoration (Kroncke, 1970). A Cochrane review found insufficient evidence to conclude whether restorations failed less often after TCE compared with IPC, but data were available for the primary dentition only (Ricketts et al., 2013). The third argument for TCE was that it prevents further cariogenic activity (Kroncke, 1970). However, it has been demonstrated that bacteria still persist in deep carious lesions treated by TCE (Crone, 1968; Shovelton, 1968; Lager et al., 2003). It has also been shown that remaining dentine was more infected after TCE than after IPC covered with a calcium hydroxide (CH) base material and sealed for 6-7 months (Maltz et al., 2012b) (Table 1).

A Cochrane review showed a 49% lower risk of pulpal exposure during SWE compared to TCE for permanent teeth and a 69% lower risk of pulpal exposure in primary and permanent teeth during IPC compared to TCE, but observed no evidence of a differences in the signs and symptoms of pulpal disease (Ricketts et al., 2013). Another systematic review and meta-analysis investigating primary and permanent teeth showed a 69% decreased risk of pulpal exposures and a 42% reduction in pulpal symptoms in teeth treated with SWE and IPC combined compared to teeth treated with TCE, but found a similar risk of restoration failures (Schwendicke et al., 2013a). A randomized clinical trial (RCT) demonstrated a significantly lower 1-year follow-up success rate of TCE (62%) compared to SWE (74%) in adults (Bjørndal et al., 2010) (Table 1).

Stepwise excavation

In the 18th century, Fauchard recommended partial caries excavation in order to avoid pulpal exposure, followed by Tomes in the 19th century (cited in Jordan and Suzuki, 1971). This treatment was based on the theory that a zone of affected dentine laying between the outer
infected layer and the pulp would be able to remineralize (Fusayama and Terachima, 1972; Miyauchi et al., 1978). Fuchsin was suggested as a caries detector dye to discriminate between the two layers (Fusayama, 1979). Other studies have demonstrated that the use of caries detector dye resulted in over-excitation of carious dentine, and concluded that tactile and optical criteria, such as a soft, moist texture, but not color, are satisfactory to detect infected dentine (Kidd et al., 1993a; b; Kidd et al., 1996). Preoperative treatment when most of carious dentine was removed has been advocated in the past (Bodecker, 1938; Kerkhove et al., 1967). The amount of dentine removed during the first step of SWE has decreased during the time (Massler, 1967; Leksell et al., 1996).

The aim of the first step of SWE is to remove superficial parts of infected dentine from the lesion’s floor and perform a complete excavation of the peripheral parts of the lesion, thus avoiding pulpal exposure, arresting caries progression, promoting healing of the affected dentine, and stimulating pulpal defense by increasing the dentine barrier (Bjørndal et al., 1997; Bjørndal and Darvann, 1999). After this re-entry is performed, the goal of which is to remove residual demineralized dentine that may be infected and could slowly progress (Bjørndal et al., 1997). However, pulpal exposure may occur during re-entry (Bjørndal and Thystrup, 1998; Bjørndal et al., 2010; Orhan et al., 2010; Maltz et al., 2012a) (Table 1).

Changes in dentine color (darker), consistency (harder), moisture (drier), and microflora (less cariogenic) on re-entry indicate arrested caries in deciduous and permanent teeth, irrespective of the material used or the thickness of residual dentine (King et al., 1965; Bjørndal et al., 1997; Bjørndal and Thystrup, 1998; Bjørndal and Larsen, 2000; Maltz et al., 2002; Corralo and Maltz, 2013) (Table 1). Drastically reduced bacterial counts have been reported under sealed restorations, but they were still present (King et al., 1965; Bjørndal et al., 1997). A Cochrane review concluded that there was insufficient evidence as to whether re-entry was necessary, as studies that did not use re-entry reported no adverse consequences (Ricketts et al.,
A RCT on young permanent teeth with deep carious lesions showed a 94%-95% success rate of both SWE and IPC after 1 year of follow-up (Orhan et al., 2010) (Table 1). Another RCT investigating permanent teeth demonstrated success rates of 69% and 91% for SWE and IPC, respectively, after 3 years of follow-up (Maltz et al., 2012a) (Table 1). Re-entry in SWE seemed to be disadvantageous not only due to the increased risk of pulpal exposure, but also because patients do not show up for their re-entry appointments. Incomplete SWE decreases the success rate of the procedure tremendously (13%) compared to complete SWE (88%) (Maltz et al., 2012a). A systematic review of studies of primary and permanent teeth found a 79% reduced risk of tooth failure after IPC compared to SWE (Schwendicke et al., 2013c).

**Indirect pulp capping**

Traditional IPC consists of leaving a layer of carious dentine under the permanent restoration to prevent carious exposure (Eidelman et al., 1965; Fitzgerald and Heys, 1991). Before permanent restoration is performed, the carious lesion is treated with a capping material, usually CH, which significantly reduces the number of residual bacteria and arrests the carious process, giving the pulp a chance to recover and produce tertiary dentine (Leung et al., 1980). The disadvantage when using CH is that it might dissolve and thus fail to provide a tight seal (Prosser et al., 1982; Phillips et al., 1984). Caries may progress rapidly if the seal breaks down. A recent RCT investigating primary teeth concluded that IPC with non-resorbing materials, such as mineral trioxide aggregate (MTA) or medical Portland cement, was preferable to CH slurry (Petrov et al., 2014). Another approach is to restore deep carious lesions directly with an adhesive resin system (Falster et al., 2002). One study on carious lesions of moderate depth demonstrated excellent 10-year results in lesions without carious dentine removal but with good sealing (Mertz-Fairhurst et al., 1998). Hermetical restoration prevents nourishment from reaching bacteria, isolating them and leading to either death or dormancy (Oong et al., 2008).
Recently, a less invasive approach to IPC was adopted. It is performed in a similar manner to the first step of SWE, i.e., by removing central parts of the carious lesion superficially and peripheral parts completely (Gruythuysen et al., 2010; Maltz et al., 2011; Maltz et al., 2012a) (Table 1). A systematic review and meta-analysis investigating primary and permanent teeth demonstrated an 80% lower risk of carious exposure during IPC compared to TCE, but concluded that it was too early to make clinical recommendations (Schwendicke et al., 2013a). IPC may also lead to root canal obliteration, which can complicate endodontic treatment if it is needed later on (Woehrlen, 1977).

2.5. Treatment options for carious exposures

During the excavation of deep carious lesions, the barrier of residual dentine may be broken, causing carious exposure that usually occurs under acute, rapidly penetrating carious lesions (Massler, 1967). In this context, the dilemma is whether to preserve tooth vitality or to perform pulpectomy followed by root canal treatment.

Vital pulp therapy

Vital pulp therapy (VPT) refers to three procedures, all of which aim to preserve tooth vitality despite pulpal exposure (Goodis, 2012) (Table 2). The first is direct pulp capping (DPC), a procedure in which exposed pulp is covered with a capping material after the bleeding has been stopped (Haskell et al., 1978; Baume and Holz, 1981; Dammaschke, 2008). The second is called partial pulpotomy (PP), i.e., when part of the coronal pulp adjacent to an exposure is removed and the rest of the pulp is covered with a capping material (Cvek, 1978). Finally, pulpotomy is a procedure where the entire crown pulp is removed from the pulp chamber and the remaining root pulp at the orifices of the root canals is covered with a capping material (Zander, 1939). The first report of VPT in the literature was in 1756, when Philip Pfaff attempted to perform DPC with small pieces of gold (cited in Glass and Zander, 1949). In a laboratory setting under
Table 2. Overview of studies on the treatment of carious exposures in permanent teeth.

<table>
<thead>
<tr>
<th>AUTHOR</th>
<th>DESIGN</th>
<th>NUMBER OF TEETH*, AGE OF SUBJECTS</th>
<th>ORIGIN OF EXPOSURE**, PULPAL STATUS</th>
<th>TREATMENT, MATERIAL(S)</th>
<th>CONTR OL</th>
<th>FOLLOW-UP</th>
<th>RESULTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haskell et al., 1978</td>
<td>Retrospective</td>
<td>n=149, 8-75 years</td>
<td>Carious exposures, Asymptomatic teeth</td>
<td>DPC, CH (powder) Penicillin</td>
<td>-</td>
<td>5-22 years (mean 11.7)</td>
<td>Success rate (vital pulp, absence of symptoms and periapical lesion): 5 years 87.3%, &gt; 5 years 76.5%</td>
</tr>
<tr>
<td>Hørsted et al., 1985</td>
<td>Retrospective</td>
<td>n=80, 10-79 years</td>
<td>Deep carious lesions, carious exposures, No history of pain</td>
<td>DPC CH (Dycal, Pulpdent, slurry)</td>
<td>-</td>
<td>5 years</td>
<td>Success rate (vital pulp, absence of history of pain, periapical lesion and sensitivity to percussion): 78.6%</td>
</tr>
<tr>
<td>Barthel et al., 2000</td>
<td>Retrospective</td>
<td>n=54 5 years n=69 10 years, 10-70 years</td>
<td>Deep carious lesions, carious exposures, No history of pain</td>
<td>DPC CH (Life)</td>
<td>-</td>
<td>5 years 10 years</td>
<td>Success rate (vital pulp, absence of clinical symptoms and periapical lesion): 5 years 37%, 10 years 13%</td>
</tr>
<tr>
<td>Bogen et al., 2008</td>
<td>Prospective</td>
<td>n=49, 7-45 years (mean 16.6)</td>
<td>Deep carious lesions, carious exposures, Reversible pulpsitis at most, moderate-severe pain included</td>
<td>DPC MTA (grey and white MTA, ProRoot)</td>
<td>-</td>
<td>1-9 years (mean 4)</td>
<td>Survival rate (vital pulp, absence of pain and periapical lesion): 97.96%</td>
</tr>
<tr>
<td>Mente et al., 2010</td>
<td>Retrospective</td>
<td>n=59 MTA n=47 CH, 8-78 years (median 40)</td>
<td>Carious exposures, Reversible at most</td>
<td>DPC CH (Hyposal SN)</td>
<td>DPC MTA (grey and white, ProRoot)</td>
<td>1-6.7 year</td>
<td>Success rate (vital pulp, absence of clinical signs and symptoms, periapical lesion and internal root resorption, no loss of function): CH 62%; MTA 80%</td>
</tr>
<tr>
<td>Hilton et al., 2013</td>
<td>PBRN** RCT</td>
<td>n=183 MTA n=175 CH, ≥7 years</td>
<td>Carious, traumatic, or mechanical exposures, Reversible at most</td>
<td>DPC MTA (ProRoot)</td>
<td>DPC CH (Life)</td>
<td>Median 12.1 months for CH group and 15.6 months for MTA group</td>
<td>The probability of failure (signs of periapical pathology on radiograph, recommendation for tooth extraction or root canal treatment): CH 31.5%; MTA 19.7%</td>
</tr>
<tr>
<td>Study</td>
<td>Design</td>
<td>n</td>
<td>Population</td>
<td>Procedure</td>
<td>Follow-up</td>
<td>Results</td>
<td></td>
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</table>
| Cho et al., 2013 | Retrospective | n=175 | Carious exposures, Reversible pulpitis at most | DPC CH (Dycal) | 1 year | Survival rate (absence of spontaneous or lingering pain to stimuli, periapical lesion and root canal treatment): 1 year CH 73.9%; MTA 89.9%, 3 years CH 52.5%; MTA 67.4%.
| Mente et al., 2014 | Retrospective | n=127 MTA n=49 CH, 7-78 years (median 44) | Carious exposures, Reversible pulpitis at most | DPC CH (Hyposal SN) | 2-10.25 years (median 3.5) | Success rate (absence of clinical signs and symptoms, PAI <2, absence of pathology on radiograph, root canal treatment, loss of function and extraction): CH 57%; MTA 80%.

**Studies investigating DPC in adults**

<table>
<thead>
<tr>
<th>Study</th>
<th>Design</th>
<th>n</th>
<th>Population</th>
<th>Procedure</th>
<th>Follow-up</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fitzgerald &amp; Heys, 1991</td>
<td>Prospective</td>
<td>n=19 CH (Life) n=19 CH (Dycal), 20-60 years</td>
<td>Deep carious lesions, but pulpal exposure not expected, Reversible pulpitis at most</td>
<td>DPC CH (Life)</td>
<td>12 months</td>
<td>No sig. difference in symptoms between materials. Sig. increase in symptoms from pretreatment and one week post-treatment and decrease from one week to six months post-treatment.</td>
</tr>
<tr>
<td>Matsuo et al., 1996</td>
<td>Prospective</td>
<td>n=44, 20-69 years (mean 42)</td>
<td>Deep carious lesions, carious exposures, Lingering pain on stimuli and spontaneous pain included</td>
<td>DPC CH (Dycal or Life)</td>
<td>≥3 months</td>
<td>Success rates (vital pulp, absence of signs and symptoms of irreversible pulpitis and periapical lesion): 3 months 81.8%</td>
</tr>
<tr>
<td>Miles et al., 2010</td>
<td>Retrospective</td>
<td>n=51, 21-85 years (mean 42)</td>
<td>Carious exposures, Asymptomatic teeth</td>
<td>DPC MTA</td>
<td>1-2.5 years</td>
<td>Survival rate (vital pulp, absence of signs and symptoms of irreversible pulpitis and periapical lesion, no endodontic treatment or extraction): 1 year 68%, 2 years 56%</td>
</tr>
</tbody>
</table>

**Studies investigating PP in mixed age groups (children and adults)**

<table>
<thead>
<tr>
<th>Study</th>
<th>Design</th>
<th>n</th>
<th>Population</th>
<th>Procedure</th>
<th>Follow-up</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass &amp; Zilberman, 1993</td>
<td>Prospective</td>
<td>n=35, 7.5-25 years (mean 12.5)</td>
<td>Very deep carious lesions, Recent short duration pain included</td>
<td>PP CH (Calxyl)</td>
<td>≥12 months</td>
<td>Success rate (vital pulp, absence of clinical symptoms and pathology on radiograph): 91.4%</td>
</tr>
<tr>
<td>Mejare &amp; Cvek, 2010</td>
<td>Prospective</td>
<td>n=31 no clinical or radiographic symptoms</td>
<td>Deep carious lesions,</td>
<td>PP CH (Calasept)</td>
<td>2-11.7 years</td>
<td>Success rates (vital pulp, absence of clinical symptoms and pathology on</td>
</tr>
</tbody>
</table>

27
<table>
<thead>
<tr>
<th>Year</th>
<th>Study Design</th>
<th>n</th>
<th>Description</th>
<th>Treatment</th>
<th>Success Rate</th>
<th>Duration</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1993</td>
<td>Prospective</td>
<td>6</td>
<td>Clinical and/or radiographic symptoms 6-15 years (mean 9)</td>
<td>PP CH (Calasept)</td>
<td>-</td>
<td>14-33 months</td>
<td>No pain or temporary pain radiograph: no symptoms group 93.5%; symptoms group 4 out of 6.</td>
</tr>
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<td></td>
<td>Success rate (vital pulp, normal percussion, absence of complains and sensitivity to percussion): 100%</td>
</tr>
<tr>
<td>1998</td>
<td>Prospective</td>
<td>31</td>
<td>Large carious lesions, Unknown pulpal status 10-15, 20-27 years</td>
<td>PP Grey MTA (ProRoot)</td>
<td>-</td>
<td>12-26 months</td>
<td>Responsive to vitality testing: 79% Dentinal bridge formation: 64%</td>
</tr>
<tr>
<td>2006</td>
<td>Prospective</td>
<td>23</td>
<td>Deep carious lesions, Reversible pulpitis at most 7.2-13.1 years (mean 10)</td>
<td>PP Grey MTA (ProRoot)</td>
<td>PP CH (Hypocal +Dycal)</td>
<td>2-3.8 years</td>
<td>Success rate (absence of history of pain, swelling, pathology on radiograph and sensitivity to percussion): CH 91%; MTA 93%</td>
</tr>
<tr>
<td>2007</td>
<td>RCT</td>
<td>41</td>
<td>Deep occlusal carious lesions, Reversible pulpitis at most</td>
<td>PP MTA (ProRoot)</td>
<td>PP CH (Dycal)</td>
<td>2 years</td>
<td>Incidence rate/100 tooth-month (95% CI) (pain, swelling, sensitivity to percussion, periapical or furcation lesion, root resorption or lack of root development in immature tooth): CH 0.11 (0.001–0.60); MTA 0.20 (0.02–0.71)</td>
</tr>
<tr>
<td>2010</td>
<td>RCT, multi-center</td>
<td>22</td>
<td>≥3/4 into dentine with well-defined radiodense zone, Reversible pulpitis at most, mild pain included</td>
<td>DPC CH (Dycal)</td>
<td>PP CH (Dycal)</td>
<td>407-531 days DPC 390-530 days PP</td>
<td>Success rate (vital pulp, absence of unbearable pain and periapical lesion): DPC 31.8%; PP 34.5%</td>
</tr>
</tbody>
</table>

Studies investigating DPC versus PP in adults

Bjørndal et al., 2010

1 Number of teeth analyzed.
2 In case of carious exposure, the depth of the lesion is indicated if given in the original article.
3 Practise-based research network
germ-free conditions, surgically-exposed pulps resulted in wound-healing reactions (Kakehashi et al., 1965). Studies have reported healing after surgical exposures and complicated crown fractures when covered with CH (Glass and Zander, 1949; Cvek, 1978). Therefore, VPT was indicated mainly for mechanic and traumatic exposures (Dammaschke, 2008). In the case of carious exposure, the capping material is applied to the pulp that is inflamed and exposed to bacteria in the oral cavity (Massler, 1967; Massler and Pawlak, 1977). In the event of carious exposure the odontoblast layer is lost. The progenitor cells from the pulp are recruited to the pulpal wound and differentiated into odontoblast-like cells. Healing is promoted by the secretion of dentine-like tissue (Smith and Lesot, 2001; Ricucci et al., 2014a). Any capping material should be bactericidal and should initiate the release of signaling molecules necessary for the induction of dentine-like tissue secretion upon interaction with dentine (Graham et al., 2006; Tomson et al., 2007; Ferracane et al., 2010). CH is considered the standard material for VPT because it has a high pH that provides bactericidal activity and stimulates the secretion of dentine-like tissue (Schroder, 1985; Sangwan et al., 2013). However, there are indications that the sealing ability of CH is not optimal; the material might dissolve, causing bacterial leakage and secondary infection (Prosser et al., 1982; Phillips et al., 1984). MTA was introduced more than 2 decades ago for the repair of lateral root perforations and as a root-end filling material (Lee et al., 1993; Torabinejad et al., 1993). Soon it was also suggested for pulp capping (Pitt Ford et al., 1996). The main soluble component of MTA is CH, which dissolves to calcium and hydroxyl ions, but the clinical behavior of MTA and CH differs (Fridland and Rosado, 2005). MTA prevents bacterial leakage better than CH due to its superior sealing ability. Moreover, MTA causes less initial inflammatory response, releases more dentine matrix proteins (TGF-β1, is a key factor in reparative dentinogenesis), raises the expression of proteins involved in dentine-like tissue formation (osteopontin, osteonectin, osteocalcina) in osteoblast-like cells and fibroblasts, and results in faster and higher quality (thicker and fewer tunnel defects)
dentine-like tissue formation (Torabinejad et al., 1995; Téclès et al., 2008; Ferracane et al., 2010; Parirokh and Torabinejad, 2010; Torabinejad and Parirokh, 2010; Laurent et al., 2012).

For young permanent teeth with carious exposures, VPT (in all cases PP) with CH showed excellent results, with success rates of 91%-94% (Mass and Zilberman, 1993; Mejäre and Cvek, 1993; Nosrat and Nosrat, 1998; Qudeimat et al., 2007). No statistically significant difference in the excellent success rate of VPT was observed when MTA and CH were compared in young permanent teeth in two RCTs (Qudeim at et al., 2007; Chailertvanitkul et al., 2013). Thus it was concluded that, in adolescents, VPT with CH works just as well as VPT with MTA.

Direct pulp capping

In mature permanent teeth with carious exposures, DPC may initially produce success rates comparable to those of endodontic treatment (Hørsted et al., 1985; Matsuo et al., 1996), but the procedure has not demonstrated long-term success (Barthel et al., 2000) (Table 2). Indeed, a low success rate (32%) was observed after 1 year of follow-up of carious exposures capped with CH in adults (Bjørndal et al., 2010) (Table 2). A much higher success rate (95%) was achieved when MTA was used as a capping material in permanent teeth with carious exposures both in adolescents and adults (Bogen et al., 2008) (Table 2). DPC with MTA revealed higher success rates (80.3%-80.5%) than DPC with CH (59%-68.5%) (Hilton et al., 2013; Mente et al., 2014) (Table 2). As these studies included pulpal exposures of both mechanic and traumatic origin, and patients from all age groups, including children, their capability to assess the success rate of DPC over carious exposures in adults is limited (Table 2). So far, there are no RCTs on DPC that compare CH and MTA, and that are restricted to carious exposures in adult patients only. Thus, using VPT instead of pulpectomy followed by root canal treatment in adults is poorly justified.
Partial pulpotomy

PP is an alternative to DPC in carious exposures. Theoretically, it has more advantages and a more predictable outcome than DPC. This is because the introduction of infected dentine chips into the pulp is prevented, superficially inflamed pulp tissue is removed, and space is made for a bacteria-tight seal (Trope et al., 2002; Aguilar and Linsuwanont, 2011). Two follow-up studies showed a 100% success rate after PP with CH for seven mature teeth in young adults (Mass and Zilberman, 1993; Nosrat and Nosrat, 1998), whereas a RCT demonstrated a low success rate for PP (34.5%) and no significant superiority of PP compared to DPC (31.8%) in adults when CH was used as a capping material (Bjørndal et al., 2010).

Pulpotomy

Pulpotomy goes back as far as the work of Codman (1851), and consists of the removal of the entire crown pulp (cited Zander, 1939). Pulpotomy has been recommended in vital, exposed young permanent teeth to promote apexogenesis (Berk, 1957). For adults pulpotomy is used as an emergency treatment (Hasselgren and Reit, 1989). Recently, promising preliminary histological and clinical results have been presented for pulpotomy with MTA as a permanent treatment of deep carious lesions in teeth with signs of reversible and irreversible pulpitis (Barngkgei et al., 2013; Simon et al., 2013).

Pulpectomy (followed by root canal treatment)

If VPT fails, endodontic treatment is the final option. Pulpectomy followed by endodontic treatment is appropriate for carious exposures in mature teeth (Hasselgren, 2008) and is the most predictable treatment methods, although the corresponding long-term success rates vary greatly (60%-100%) (Kojima et al., 2004; Ng et al., 2007; Ng et al., 2010). Endodontic treatment has several disadvantages: i) it is expensive and time-consuming; ii) it increases the probability of tooth fracture due to more coronal destruction (compared with VPT) and loss of
proprioseptive response; and iii) it is impossible to protect against bacterial invasion if vital pulp is lost (Lewis and Smith, 1988).

2.6. The treatment dilemma

Systematic reviews on the treatment of deep carious lesions showed that the level of evidence is currently insufficient for definitive conclusions to be drawn regarding the most effective treatment method, as most of the included studies had only short-term follow-up and a high risk of bias (Bergenholtz et al., 2013; Miyashita et al., 2007). Surveys from the USA, Brazil, Germany, and Sweden, showed no uniform treatment method, further demonstrating the uncertainty regarding the best treatment of deep carious lesions and carious exposures (Oen et al., 2007; Weber et al., 2011; Frisk et al., 2013; Schwendicke et al., 2013b). The majority of the dental practitioners (50%-80%) preferred TCE for the treatment of deep carious lesions in mature teeth in adults; in the case of carious exposure, DPC was preferred by 53%-83%. However, the treatment methods preferred by general dental practitioners (GDPs) in Northern Norway are unknown.
3. AIMS

The aims of this thesis were:

- to document the prevalence of deep carious lesions and other consequences of caries (DCL-CC) among 18-year-olds in Troms County, Northern Norway.
- to analyze the association between DCL-CC and various background factors: gender, urban/rural clinic location, history of medical problems, bitewing examination intervals and DMFT score.
- to investigate the preferred treatment methods and routines for treating deep carious lesions in vital, permanent, mature teeth among GDPs in Northern Norway.
- to disclose factors behind GDPs’ preferred treatment methods.
- to investigate whether pulps of molars presenting carious exposure and directly capped with MTA survived longer than pulps directly capped with CH in adult patients.
4. MATERIALS AND METHODS

4.1 Subjects

*Study I, cross-sectional age cohort study*

The study population sample consisted of all individuals (n=1978) born in 1993 and enrolled in the PDHS in Troms County at the time of the study. The final study sample consisted of 1876 subjects with digital bitewing radiographs in their electronic dental records (Opus Dental software, Opus Systemer AS, Nesbru, Norway); 102 individuals were excluded due to lack of digital bitewing radiographs. The most recent digital bitewing radiographs and dental records of each subject were examined.

*Study II, survey*

The study sample consisted of all (N=437) GDPs working in Northern Norway (Nordland, Troms, and Finnmark Counties). GDPs’ names and home or work addresses were retrieved from the professional registers by the chief dental officers or local dental associations. Questionnaires and invitation letters were sent via mail, and 37 questionnaires were returned due to lack of relevance. Thus the final study sample consisted of 400 GDPs.

*Study III, randomized clinical trial*

Sample size calculation was based on an estimated 30% difference in the success rates of MTA and CH. The success rate in the CH group was set to 55% after 2 years according to Barthel and colleagues (2000). With a significance level of 5% and a power of 95%, we calculated that 64 subjects were needed in each group. When the drop-out rate of 20% was included, the final goal for recruitment was 160 subjects. Subjects were recruited from three public dental clinics in Northern Norway and one private dental clinic in Lithuania. To be eligible, subjects had to meet strict inclusion criteria: i) caries in first or second permanent molars (only one tooth per subject); ii) presence of proximal caries; iii) age 18-55 years; and iv) non-contributory medical history (including pregnancy). Subjects were excluded if they i) had no pulpal exposure during
treatment; or ii) had bleeding of the exposed pulp that could not be controlled in 10 minutes. In total, 80 subjects were enrolled in the study, 10 of which were excluded due to no pulpal exposure. Thus the total study sample consisted of 70 subjects, who were randomly assigned to either the MTA group (n=33) or the CH group (n=37).

4.2 Methods

Study I, cross-sectional age cohort study

This cross-sectional study was conducted in Troms County during the spring of 2012. We used the most recent digital bitewing radiographs taken before the onset of this study as part of routine dental screening. These radiographs were retrieved from electronic dental records (Opus Dental software, Opus Systemer AS, Nesbru, Norway) and the molar region (except third molars) of each study subject was examined. DCL-CC (deep carious lesions, deep restorations, root canal obturated molars and extractions due to caries) were recorded using tooth as a unit. Deep untreated carious lesions and deep restorations were determined as those reaching the inner ¼ of the dentine (Bjørndal et al., 2010).

Before data collection by the main investigator (LS), calibration was performed in collaboration with a maxillofacial radiologist (NLB) and inter- and intra-observer reliability was calculated. The inter-observer reliability (NLB and LS) rendered a Cohen’s kappa value of 0.62 and intra-observer reliability (LS) showed a kappa value of 0.87 (Cohen, 1960). Twenty digital bitewing radiographs showing 34 deep carious lesions and deep restorations at least in the inner half of dentine were selected to for the assessment of reliability.

Study II, survey

The questionnaire study was performed during the autumn of 2011. The multiple-choice questionnaire contained 20 questions and was first written in the English language (Appendix 1). The questionnaire was translated into Norwegian before it was mailed to the subjects.
Variables of interest were: i) preferred treatment methods for deep carious lesions and carious exposures in mature permanent teeth in the absence and presence of symptoms; ii) demographic characteristics of subjects; iii) reasons and factors (options listed) why subjects preferred their chosen treatment method; iv) deep caries treatment routine (instrument and materials used). Content validity was tested by four dental postgraduate students.

The questionnaire was mailed to all subjects along with a personalized invitation letter (Appendix 2) and a coded, pre-paid return envelope. After 8 weeks, an identical set was mailed to non-responders, identified by the code on the envelope. After an additional 8 weeks, five randomly selected non-respondents were contacted by phone to identify the reason for non-response. After a total of 16 weeks the survey was closed.

Study III, randomized clinical trial

In order to assess the long-term survival of pulps after DPC performed with either white ProRoot® MTA (Dentsply, Tulsa Dental, Tulsa, OK, USA) or CH (Dycal®, Dentsply DeTrey GmbH, Konstanz, Germany) over carious exposure, a multicenter, single-blinded RCT was conducted. Balancing randomization was done centrally, at the Department of Clinical Dentistry, UiT the Arctic University of Norway, using an envelope method. Each recruitment clinic served as an allocation unit. Twenty envelopes with block sizes 4-6-4-6 were sent to the participating clinics. Group allocation was not shared with the subjects.

Written informed consent was obtained from each subject (Appendix 3). Paper instructions regarding the study were presented to the GDPs. In order to ensure that DPC was performed in a uniform manner across the clinics, GDPs in Norway met with the main investigator (RK) to demonstrate how DPC should be performed for the study. The GDP in Lithuania met with another author (LS) for this purpose. The results of DPC and the confidential patient number were recorded (Appendix 4) and reported to the main investigator. Follow-up was planned at 1 week and at 6, 12, 24, and 36 months after the procedure, as it has been shown
that at least 21 months of follow-up is necessary for proper outcome assessment (Matsuo et al., 1996). According to the schedule, the recruitment of study subjects was terminated in spring 2013. The primary outcome of the study was survival rate of the capped pulps and the secondary outcome was postoperative pain at 1-week follow-up.

4.3 Statistics

The statistical methods used in the studies are explained in detail in the original articles and summarized in Table 3.

Table 3. Overview of the statistical analyses used in the studies.

<table>
<thead>
<tr>
<th>Statistical program package</th>
<th>Study I</th>
<th>Study II</th>
<th>Study III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statistical program package</td>
<td>IBM SPSS 19</td>
<td>IBM SPSS 21</td>
<td>IBM SPSS 21</td>
</tr>
<tr>
<td>Cohen’s kappa</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Pearson’s chi-square test</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Mann-Whitney test</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Logistic regression analysis</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Log-Rank (Mantel-Cox) test</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
</tbody>
</table>

In addition, in Study I the variable DMFT score was calculated using mathematical coupling (Walsh and Lee, 1998). In Study III the baseline imbalance between groups regarding the depth of carious lesions assessed from radiographs was analyzed by a stratified long-rank test (Altman, 1985).

4.4 Ethical considerations

Study I, cross-sectional age cohort study

This study included data from PDHS dental records and digital bitewing radiographs. The Regional Ethical Committee of Northern Norway considered that the study fell within the
framework of a Quality Assurance Project and that ethical approval was therefore unnecessary (2011/2492/REK nord).

**Study II, survey**

This study included no patient information. Ethical approval was considered unnecessary by the Regional Ethical Committee of Northern Norway.

**Study III, randomized clinical trial**

The participation in this RCT was voluntary and written informed consent was obtained from all study subjects. Ethical approval (2010/2112-4) was obtained on 14.09.2010 from the Regional Ethical Committee of Northern Norway. The RCT is registered in ClinicalTrials.gov.
5. MAIN RESULTS

Study I, cross-sectional age cohort study

The outcome in Study I was recorded from the most recent digital bitewing radiographs, the majority of which were taken in 2011; for 8.5% of subjects bitewing radiographs were taken in 2010, for 4.4% in 2009, for 1.1% in 2008, and for 0.4% of subjects the most recent digital bitewing radiographs were taken between 2007 and 2005. Among 18-year-olds in Troms County (n=1876) there were 488 (26%) having at least one molar with DCL-CC. The most prevalent modality of DCL-CC was deep restoration; at least one molar with deep restoration was observed among 21.5% (n=404) of the age cohort (Fig. 3). Deep restoration was followed by root canal obturated molars, molars extracted due to caries, and untreated deep carious lesions, which were present in 5.1%, 3.6%, and 1.6% of this age cohort, respectively (Fig. 3).

Figure 3. Distribution of 18-year-olds (n=1876) according to DMFT score and presence of DCL-CC in permanent molars.
Of the 15008 molars analyzed, there were 848 (6%) with DCL-CC. The same pattern was observed, with the most prevalent modality of DCL-CC being deep restorations (70%) and the least prevalent modality being untreated deep carious lesions (4%) (Fig 4).

**Figure 4.** A) Distribution of permanent molars (n=15008) according to the presence/absence of DCL-CC. B) Distribution of 848 molars by modality of DCL-CC: untreated deep carious lesions, deep restorations, root canal obturations, extractions due to caries.

Out of 1876 18-year-olds, there were 206 (11%) with a DMFT score of zero. Four hundred and eighty-eight subjects with DCL-CC had a mean DMFT (SD) score of 9.1 (4.6) and a median DMFT score of 8 (range 1-25), which was more than double the mean DMFT (SD) score of 4.5 (4.0) (p<0.001) and median DMFT score of 4 (range 0-21) observed among subjects without DCL-CC. According to the univariable binary logistic regression analysis, DMFT score
was associated with all modalities of DCL-CC (p<0.001). A DMFT score higher than 5 was associated with a self-reported history of medical problems (odds ratio, OR=1.5, CI 1.02-2.09) and with a 6-month decrease in bitewing examination intervals (OR=0.7, CI 0.7-0.8).

Records on recall dates were available for 93 subjects having DCL-CC and recall intervals could be calculated for 83 of them. The mean (SD) length of recall intervals were 16.1 (7.1) months and the median length was 13.35 months (range 5-40 months).

A 1-unit increase in DMFT score was associated with an OR of 1.3, while a 6 month increase in bitewing examination intervals associated with an OR of 1.5 for untreated deep carious lesions (Table 4).

Table 4. OR for having at least one molar with untreated deep carious lesion (versus no DCL-CC) according to background factors retrieved by binary logistic regression.

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>Crude OR Univariable analysis OR (95% CI), p</th>
<th>Adjusted OR viii Multivariable analysis OR (95% CI), p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female gender (vs male)</td>
<td>0.5 (0.2-1.02), NS</td>
<td>0.5 (0.2-1.2), NS</td>
</tr>
<tr>
<td>Rural location of clinic (vs urban)</td>
<td>0.6 (0.2-1.4), NS</td>
<td>0.7 (0.2-1.8), NS</td>
</tr>
<tr>
<td>Medical problems (vs healthy)</td>
<td>1.6 (0.5-5.3), NS</td>
<td>1.8 (0.5-6.7), NS</td>
</tr>
<tr>
<td>DMFT score ix (continuous)</td>
<td>1.2 (1.2-1.3), 0.000 ix vii</td>
<td>1.3 (1.2-1.4), 0.000 x</td>
</tr>
<tr>
<td>Bitewing examination interval</td>
<td>1.3 (1.004-1.8), 0.047 ix vii</td>
<td>1.5 (1.1-2.1), 0.005 x</td>
</tr>
<tr>
<td>Explained variance</td>
<td>-</td>
<td>0.202</td>
</tr>
<tr>
<td>Nagelkerke R²</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

viii Adjusted for all independent variables.
ix DMFT score is calculated by mathematical coupling (subtracting the number of molars with DCL-CC from the overall DMFT score).
x p <0.05.
A 1-unit increase in DMFT score and self-reported history of medical problems was associated with ORs of 1.2 and 3.2, respectively, for extractions due to caries (Table 5). These results are slightly different from those published in Study I due to statistical analyses using the mathematical coupling calculation of the DMFT score (Walsh and Lee, 1998). Urban/rural location of the clinic, which represented a socio-economic factor, did not yield a significant association with either DMFT score or DCL-CC.

**Table 5. OR for having at least one molar extracted due to caries (versus no DCL-CC) according to background factors retrieved by binary logistic regression. DMFT score represents subtraction of DMFT score from the number of teeth with deep carious lesions.**

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>Crude OR Univariable analysis OR (95% CI), p</th>
<th>Adjusted OR\textsuperscript{\textsubscript{xi}} Multivariable analysis OR (95% CI), p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female gender (vs male)</td>
<td>0.8 (0.4-1.3), NS</td>
<td>1.1 (0.6-1.9), NS</td>
</tr>
<tr>
<td>Rural location of clinic (vs urban)</td>
<td>1.8 (1.1-2.9), 0.023</td>
<td>1.6 (0.9-2.9), NS</td>
</tr>
<tr>
<td>Medical problems (vs healthy)</td>
<td>3.3 (1.7-6.3), 0.000\textsuperscript{\textsubscript{xii}}</td>
<td>3.2 (1.5-6.7), 0.002\textsuperscript{\textsubscript{xii}}</td>
</tr>
<tr>
<td>DMFT score\textsuperscript{xiii} (continuous)</td>
<td>1.2 (1.1-1.3), 0.000\textsuperscript{\textsubscript{xi}}</td>
<td>1.2 (1.1-1.3), 0.000\textsuperscript{\textsubscript{xi}}</td>
</tr>
<tr>
<td>Bitewing examination interval (every 6 months, continuous)</td>
<td>0.6 (0.4-0.9), 0.021\textsuperscript{\textsubscript{xi}}</td>
<td>0.9 (0.6-1.3), NS</td>
</tr>
<tr>
<td>Explained variance</td>
<td>-</td>
<td>0.146</td>
</tr>
<tr>
<td>Nagelkerke $R^2$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\textsuperscript{\textsubscript{xi}} Adjusted for all independent variables.
\textsuperscript{\textsubscript{xii}} $p < 0.05$.
\textsuperscript{\textsubscript{xiii}} DMFT score is calculated by mathematical coupling (subtracting the number of molars with DCL-CC from the overall DMFT score).

**Study II, survey**

Two hundred twenty-two of the 400 invited GDPs returned the study questionnaire (response rate of 55.5%). There were 178 respondents after the first mailing round (response rate 44.5%) and 44 after the second mailing round. There was an over-representation of publicly employed GDPs among respondents, otherwise respondents and non-respondents were similar in gender.
and in urban/rural location of the clinic. Analysis of early and late respondents showed no differences in background characteristics or preferred treatment methods. Two different scenarios were presented in the questionnaire (presence and absence of symptoms) regarding deep carious lesions and carious exposure in vital, permanent, mature teeth. Different treatment methods were preferred by GDPs in each scenario (Fig. 5). VPT, i.e. TCE (49%) and SWE (45%), was the preferred treatment method for deep carious lesions in the absence of symptoms. Pulpectomy followed by endodontic treatment (39%) and SWE (38%) were almost equally preferred treatment methods for deep carious lesions with symptoms. In cases of carious exposure, the presence of symptoms (indicating reversible pulpitis at most) was statistically significantly associated with pulpectomy followed by root canal treatment as the preferred treatment method ($\chi^2=120$, d.f.=1, $p<.001$). DPC (51%) was the preferred treatment method when symptoms were absent.

Figure 5. Frequency distribution of preferred treatment methods for deep carious lesions and carious exposures in the presence/absence of symptoms.
The two most frequently chosen patient-related factors were the same ("Final restoration" and "Patient’s oral health") regardless of preferred treatment method; "Patient’s age" was the second most frequent patient-related factor chosen by GDPs whose preferred treatment method was DPC.

Most of the respondents used CH paste as a capping material when there was no carious exposure (Fig. 6). Around two-thirds of the respondents used CH paste and/or slurry as a capping material for DPC and PP and less than 20% of respondents use rubber-dam while treating carious exposures (Fig. 7).

Figure 6. Distribution (%) of treatment routines by preferred treatment method of deep carious lesion.
Figure 7. Distribution (%) of treatment routines by preferred treatment method of carious exposures.

In cases with no symptoms and no carious exposure, urban location of clinic was associated with TCE versus IPC and SWE combined (OR=2.2, CI 1.2-4.1) and TCE versus SWE (OR=2.1, CI 1.1-4.1). Graduation from dental school in Norway was associated with a lower OR for TCE versus IPC and SWE (OR=0.5, CI 0.2-0.9) and TCE versus SWE (OR=0.4, CI 0.2-0.9). Models that used TCE and SWE as dependent variables (versus IPC) did not show any statistically significant associations with subjects’ background characteristics.

In cases with symptoms but no carious exposure, urban location of clinic was associated with an OR of 2.2 (CI 1.2-4.1) for pulpectomy followed by root canal treatment (versus TCE, SWE and IPC combined. When TCE was used as the dependent variable (versus SWE and IPC individually and combined), no statistically significant association was observed with subjects’ background characteristics. The same was true when SWE was compared to IPC.

In cases with carious exposure and symptoms, graduation in Norway and 5 or more years in practice were associated with an OR for pulpectomy followed by root canal that was three times higher than that for DPC and PP combined (OR=3.1, CI 1.1-8.9 and OR=2.8, CI 1.1-7.4, respectively).
Study III, randomized clinical trial

As of January 2015, 80 subjects had been recruited, 10 of whom have been excluded due to lack of carious exposure. In total, 70 subjects were randomly assigned to either the MTA group, (n=33) or to the CH group, (n=37). Subjects in the MTA and CH groups were similar in age, molar number, cavity type, and preoperative pain, but not regarding the depth of the carious lesion, which was assessed from radiographs prior to treatment (Table 6).

Table 6. Baseline characteristics of the subjects and molars included in Study III and those excluded due to lack of carious exposure.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>MTA group n=33</th>
<th>CH group n=37</th>
<th>Lack of carious exposure n=10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age at DPC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18-29 years</td>
<td>19</td>
<td>24</td>
<td>8</td>
</tr>
<tr>
<td>30-55 years</td>
<td>14</td>
<td>13</td>
<td>2</td>
</tr>
<tr>
<td>Tooth number</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper first molar</td>
<td>13</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>Upper second molar</td>
<td>7</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>Lower first molar</td>
<td>5</td>
<td>14</td>
<td>2</td>
</tr>
<tr>
<td>Lower second molar</td>
<td>8</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Cavity type</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Occlusal</td>
<td>2</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>MOxiv</td>
<td>13</td>
<td>16</td>
<td>4</td>
</tr>
<tr>
<td>DOxv</td>
<td>11</td>
<td>11</td>
<td>6</td>
</tr>
<tr>
<td>MODxvi</td>
<td>7</td>
<td>8</td>
<td>-</td>
</tr>
<tr>
<td>Preoperative pain</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>16</td>
<td>18</td>
<td>4</td>
</tr>
<tr>
<td>No</td>
<td>17</td>
<td>19</td>
<td>6</td>
</tr>
<tr>
<td>Caries depthxvii</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2/3 into the dentine</td>
<td>6</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>&gt;2/3 into the dentine</td>
<td>15</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>Into the pulp</td>
<td>12</td>
<td>24</td>
<td>-</td>
</tr>
</tbody>
</table>

xiv Mesial-occlusal
xv Distal-occlusal
xvi Mesial-occlusal-distal
xvii Assessed from the preoperative radiograph.

46
When the depth carious lesion was dichotomized by pulpal involvement ("into the pulp" and "not into the pulp"), subjects in CH group had a statistically significantly higher number of carious lesions that were "into the pulp" ($\chi^2=5.672$, d.f.=1, $p=0.017$).

Follow-up periods ranged from 7 to 1173 days in the CH group (median 731 days) and from 4 to 1193 days in the MTA group (median 1092 days). The cumulative survival rate for the capped pulps with MTA was 80%; the rate was 46% for the pulps capped with CH (Fig. 8). This difference was statistically significant according to the log-rank test ($\chi^2=5.594$; d.f.=1; $p=0.018$). When the data were stratified according to the radiographic appearance before carious tissue excavation, the difference between the materials was not statistically significant when the assessed depth was "into the pulp" (log-rank test, $p=0.340$) (Fig. 8).

In both groups, the number of subjects with pain decreased 1 week after the procedure compared to baseline, being 16/10 and 18/8 for the MTA and CH groups, respectively. Postoperative pain was not statistically significantly associated with the material either in relieving ($\chi^2=2.862$; d.f.=1; $p=0.091$) or inducing ($\chi^2=0.557$; d.f.=1; $p=0.455$) pain. There was no statistically significant difference between preoperative pain and survival rate either in the MTA ($\chi^2=1.297$; d.f.=1; $p=0.255$) or the CH ($\chi^2=0.434$; d.f.=1; $p=0.510$) group.
Figure 8. Kaplan-Meier survival curves of molars capped with MTA and CH. Depth of carious lesions were stratified by pulpal involvement (into the pulp and not into the pulp) as assessed from radiographs taken prior to the excavation process. Schematically modified from SPSS curves.

Statistical analysis with log-rank test, $p=0.016$: MTA group estimated cumulative survival rate 85% vs. the CH group estimated cumulative survival rate 35.5% when the assessed radiographic depth of the lesion was not into the pulp.

Statistical analysis with log-rank test, $p=0.340$: MTA group estimated cumulative survival rate 71% vs. CH group estimated cumulative survival rate 50.5% when the assessed radiographic depth of the lesion was into the pulp.
6. GENERAL DISCUSSION

6.1 Consideration of methodological aspects

Study design, subjects, internal and external validity

Study I. The target population was well defined: individuals registered at the PHDS in Troms County at the time of data collection and born in 1993, making them 18 years of age at the time of the study. The PDHS is free-of-charge in Norway until the age of 18 years, therefore it was particularly convenient and interesting to study this age cohort, as they are about to leave the PDHS. All individuals who fulfilled inclusion criteria (n=1978) were included in the study except 102 who were excluded due to the lack of a digital bitewing radiograph. The study was conducted at a defined place (Troms County) and time (spring of 2012) and the results were obtained in a cross-sectional study design. According to Bhopal (2008), the function of cross-sectional studies is to measure prevalence and determine associations between disease and related factors.

Inter-observer reliability rendered a Cohen’s kappa of 0.62, which is considered substantial, and intra-observer reliability was 0.87, which is considered almost perfect; this reliability gives our study a good background for high validity (Landis and Koch, 1977). In addition, bitewing radiographs been shown to have good reproducibility and validity in epidemiological conditions (da Silva et al., 2011a; 2011b). Furthermore, a systematic review demonstrated a high correlation between radiographic prevalence of carious lesions and clinical and radiographic prevalence combined (Bloemendal et al., 2004).

In Study I, the outcome (DCL-CC) was recorded from digital bitewing radiographs. DCL-CC were strictly defined as deep carious lesions and deep restorations in the inner ¼ of dentine, root canal obturations, and extractions due to caries that were confirmed in dental records.

The study period was relatively short – 3 months (March 2012-May 2012). However, the time period covered by the data itself was a bit longer, as 14.4% of the subjects had digital
bitewing radiographs that were taken before 2011; this could have introduced mis-measurement (Bhopal, 2008). As our data included prevalent cases, the relative risk of DCL-CC could not be calculated (Szklo and Nieto, 2012). Due to the cross-sectional design of Study I, reverse causation should be considered when interpreting the associations between background factors and DCL-CC. In addition, cross-sectional studies are prone to confounding (Bray and Parkin, 2014). One way to control for confounding is to use multivariable techniques, and we did this in Study I (more in the Statistical analyses section of this doctoral thesis) (Bray and Parkin, 2014).

Study I included 95% of 18-year-olds registered at the PDHS in Troms County. This seems to be representative of the target population, and therefore generalization from the study sample to the source population is strong. However, the interpretation of study results and their generalizability beyond the source population might have some limitations. In Troms County, 85% of 18-year-olds had received dental check-ups in the PDHS in 2011, (Statistics Norway, 2011). The prevalence of caries is higher in Northern Norway compared to the rest of the country and in comparison to other Scandinavian countries, thus our results cannot be generalized to 18-year-olds in all of Norway or in other Scandinavian countries. Cross-sectional studies provide information on the care requirements of the population at a given point of time and are relevant to public health planning (Bray and Parkin, 2014). Our study indicates that the PDHS might eliminate socio-economic differences, which might be interesting for the whole of Norway, Scandinavia, and other countries with a free-of-charge PDHS.

Study II. A structured questionnaire was used to learn the preferred treatment methods of deep carious lesions among GDP working in Northern Norway. A structured questionnaire simplifies the data analysis and contributes to greater uniformity (Abramson, 1990). Content validity, which is a qualitative measurement of validity that shows whether the questions measure what they are intended to measure, was tested by four dental postgraduate students and
was evaluated as strong (Fink, 2014). Internal consistency (like Cronbach’s alpha) could not be calculated for this questionnaire due to the type of questions.

We used an invitation letter that included a visual and a written case presentation in the hopes that this would help to predict GDPs’ behavior (Appendix 2) (Jones et al., 1990). The age of the patient in the case we presented them was not indicated, but from the radiograph they could see that the root of the first upper premolar was closed and the third lower molar was erupted, indicating a young adult patient.

In order to increase the response rate, we tried to present GDPs with an interesting and relevant topic, we included a short questionnaire with a university logo, a pre-paid return envelope, and a personalized invitation letter. We also resent the questionnaire to non-respondents. However, for practical reasons, we did not record delivery/use registered mail, offer monetary incentives, or contact subjects before sending questionnaires (Edwards et al., 2007; Thorpe et al., 2009).

The final response rate was 55.5%, which is considered sufficient to represent GDPs in Northern Norway (Baruch, 1999). The background characteristics of GDPs who responded directly and those who responded only after a second questionnaire was sent did not differ. However, there was an over-representation of publicly employed GDPs, and this should be taken into consideration when interpreting our results. Self-selection bias might have been introduced, as it is possible that only those who felt confident about the topic answered (Rothman and Greenland, 2014).

**Study III.** A two-arm parallel group trial design was used to compare the two capping materials. The unit of randomization was 1 tooth per person. According to our sample size calculation, 80 subjects had to be recruited in each of the two arms. Seven dental clinics were initially included in the study, but only four of them finally recruited subjects for this RCT. For practical reasons, the recruitment of the patients did not proceed at the anticipated pace. In order
to ensure that the results were reported in a reasonable timeframe, recruitment was terminated in February 2013, even though only 80 of the originally desired 160 subjects had been recruited. As a statistically significant difference was demonstrated between the two materials, the smaller number of subjects did not cause any flaws in the study.

Dentists performing the treatment met with the investigators of the study for calibration before study onset in order to increase inter-observer reliability and to minimize bias (Juni et al., 2001). The probability of bias and confounding was reduced by proper randomization, which was ensured by creating an allocation sequence and concealing that allocation (Altman, 1991; Gluud, 2006). The allocation was concealed from the dentists by means of sealed envelopes, grouped in small blocks in order to keep the balance between groups (Altman and Bland, 1999). The envelope method has been criticized as a code that is easy to break; the block method has been criticized as it allows one to predict what comes next (Hulley et al., 2007). We chose the envelope method for logistic reasons, i.e., centralized on-line allocation was not available. Appropriate randomization allows the same chance for each study subject to be assigned to any group. However, in block randomization each patient has a chance to be allocated within the block and within the clinic, not within the study (Jadad et al., 1996). When blocking is used, the maximum difference between the numbers in the two groups should be half the block size, but 37 and 33 do not fully match half a block of 4-6-4-6, because each clinic had a separate set of envelopes (Altman and Doré, 1990).

Blinding was single, because both materials require different application techniques. The dentists performing the treatment usually examined the outcome and was not blinded, which might have introduced detection bias. Indeed, it has been shown that clinical trials that are not double-blind may have higher success rates, which is be due to bias (Juni et al., 2001). We had a low drop-out rate; only 11% of cases were lost to follow-up, four in the MTA group and four in the CH group. None of the individuals invited refused to take part in this RCT.
RCTs supply the highest grade of evidence (EBM working group, 1992). However, in Study III vulnerable groups such the age group older than 55 years, subjects with a contributory medical history and pregnant women, and subjects with periodontitis were not asked to participate, which may limit the generalizability of our study.

**Statistical analyses**

There has been much discussion on which epidemiological measurement is the most appropriate in cross-sectional studies (Hughes, 1995; Nurminen, 1995). Prevalence rates ratio (PRR) and OR are slightly different measurements and the argument against OR is that confounders might be introduced even if they do not exist (Axelson et al., 1994). Moreover, OR usually shows a stronger association then PRR, since the discrepancies between PRR and OR strongly depend on the prevalence of the exposure and the prevalence of the disease. When the prevalence of disease is very low (<10%), PRR and OR are very similar (Zocchetti et al., 1997). The use of OR in chronic disease might also be appropriate (Zocchetti et al., 1997). For the reasons mentioned above, we decided to calculate OR instead of PRR in Study I.

The use of logistic regression analysis was especially appropriate in Studies I and II, for two reasons: i) the outcomes were dichotomous (presence or absence of DCL-CC and preferred treatment method); and ii) to control for the confounding factors (Bray and Parkin, 2014). In Study I, multivariable binary logistic regression analysis was used to determine the association between DMFT score and background factors, because the variables DMFT score and bitewing examination interval did not fit the assumptions for a linear multivariable regression analysis.

We chose an arbitrary cutoff point of 5 for DMFT score. In Study I, models using the outcome untreated deep carious lesions or extractions due to caries obtained acceptable results ($p>0.05$) in the Hosmer-Lemeshow goodness-of-fit test (IBM, 2010). All potential explanatory variables were used as independent variables and were adjusted for each other. DMFT and bitewing examination interval were used as independent continuous variables. DMFT score was
calculated using mathematical coupling (subtracting the number of molars with DCL-CC from the overall DMFT score) (Walsh and Lee, 1998). The multivariable binary logistic regression model, which was used to study the association between untreated deep carious lesions and background factors, explained 20% of the variation in the outcome. The other multivariable binary logistic regression model explained 15% of the variation in the outcome.

There are two types of interaction: statistical and biological (Rothman, 2002). Statistical interaction occurs when two independent variables interact to reduce or increase risk. However, as opposed to confounding, interaction association is informative (Rothman, 2002; Bhopal, 2008). In Study I, statistical interactions were estimated on a multiplicative scale among the independent variables in Table 4 and Table 5 using multivariable binary logistic regression analyses, but none one of them were statistically significant; therefore they were not included in the further analysis.

In Study II, the associations between background characteristics and preferred treatment methods were analyzed using multivariable binary logistic regression analyses. In total, eleven models were built for 4 different scenarios. The Hosmer-Lemeshow goodness-of-fit test yielded acceptable results ($p>0.05$) (IBM, 2010) for all models.

Kaplan-Meier survival curves and the log-rank test were performed in Study III, comparing the MTA and the CH groups. This test was used in recent studies in which time to outcome was measured with success rates that varied at different time points (Cho et al., 2013; Hilton et al., 2013; Mente et al., 2014). The Kaplan-Meier survival analysis is appropriate when there is just one factor to be studied, like material. Factors other than material may influence the survival rates of teeth with carious exposures treated by VPT. However, due to the limited number of subjects, multivariable Cox regression analysis could not be used in Study III.

There was some missing data in Study I due to missing information in the dental records, and in Study II due to missing information in the questionnaire. These missing data were
ignored in the analyses, as they were not of significant magnitude and influenced sample size on a minor level. No data was missing in Study III. Data from patients lost to follow-up was included in the log-rank test due to the nature of the analysis.

6.2 Deep carious lesions and other consequences of caries in Northern Norway

For 2 decades the prevalence of deep carious lesions in Northern Norway was unknown. The findings from Study I demonstrated that more than one-quarter of 18-year-olds registered in the PDHS in Troms County at the time of our study had DCL-CC. DCL-CC represents neglected caries, and this high prevalence in a well-educated, wealthy society is of concern.

Firstly, Northern Norway has always reported inferior oral health compared to the rest of the country (Heløe et al., 1980; Wang and Riordan, 1995; von der Fehr and Haugejorden, 1997; Statistics Norway, 2012). In Study I, our study sample of 18-year-olds already had a higher DMFT score than their counterparts in Southern Norway at 12 years of age (Statistics Norway, 2015). A study among Norwegians over 20 years of age reported that living in Northern Norway was one of the predictive factors for self-perceived inferior oral health (Ekornrud and Jensen, 2010). This situation might have been caused by a lack of GDPs in the PDHS and a high turnover rate of GDPs in Northern Norway (Helse- og omsorgsdepartementet, 2007).

The high prevalence of DCL-CC in Northern Norway might also be due to non-attendance to the PDHS. Indeed, around 80% of 18-year-olds are checked at PDHS yearly, and those who do not have regular check-ups have inferior dental status (Norwegian Board of Health, 1992; Skaret et al., 1998; Statistics Norway, 2015). Long recall intervals might also be among the reasons of high prevalence of DCL-CC. In Study I very little information regarding recalls could be retrieved, as only a few subjects (19%) with DCL-CC had recall dates in their dental records. However, one would assume that bitewing examination dates reflect recall dates. In Study I, longer bitewing examination intervals (every 6 months) were associated with untreated deep carious lesions. It is unclear whether longer recall intervals are associated with
negative outcomes, such as DMFS score increment (Wang et al., 1992; Wang and Riordan, 1995; Riley et al., 2013). It also has been demonstrated that individualized recall intervals did not reduce root canal obturations and extractions due to caries, which leads to questions regarding the general benefit of individualized recall intervals (Flink et al., 2013). The bitewing examination intervals in Study I varied between 4 and 72 months and were not in accordance with recall routines in Troms County, which call for intervals of 12 to 24 months. The reason for this difference is unknown.

The importance of caries prevention in Northern Norway has been stressed, and according to a personal communication with the Chief Dental Officer in Troms County, current prevention measures seem to be in accordance with the contemporary literature (Helöe et al., 1980; Ahovuo-Saloranta et al., 201; Weyant et al., 2013). Nevertheless, the high prevalence of both high DMFT score and of DCL-CC underlines the need for improvement in the management of early carious lesions. We did not have information on how long the subjects in our study had been enrolled in the PDHS. Moreover, the nationality of subjects was not recorded in this study, thus the effect of the foreign nationality could not be assessed (Bertea et al., 2007).

Only a small fraction (4%) of DCL-CC were untreated deep carious lesions. This finding reflects the major impact the PDHS has had in Northern Norway, as half a century ago the majority of the DMFT score consisted of the D component (Helöe et al., 1980). Study I demonstrated that about every fourth 18-year-old subject had at least one molar affected by DCL-CC. However, due to slightly different methodologies used in other studies (less deep untreated carious lesions and restorations, higher number of teeth analyzed, and different age groups) the prevalence of DCL-CC could not be directly compared to that in the rest of Norway or Scandinavia (Wang and Riordan, 1995; Amarante et al., 1998; Ridell et al., 2003; Hugoson et al., 2005; Ridell et al., 2008; Grytten et al., 2013). Nevertheless, in the light of existing
Scandinavian figures, Study I suggested a more severe caries situation in Northern Norway compared to the rest of Norway or Scandinavia.

Subjects with a higher DMFT score seemed to be more prone to DCL-CC; univariate logistic regression analyses showed DMFT score to be associated with all modalities of DCL-CC. A 1-unit increase in DMFT score (calculated using mathematical coupling) was associated with untreated deep carious lesions (adjusted OR=1.3) and extractions due to caries (adjusted OR=1.2) (Tables 4 and 5). This is in line with the study by Benzian and colleagues (2011), who demonstrated a direct link between DMFT score and the number of pulpal involvements and other consequences of untreated caries in mixed dentition.

Self-reported history of medical problems was associated with a DMFT score higher than 5 (adjusted OR=1.5) and extractions due to caries (adjusted OR=3.2). This finding is in line with a study from the USA, in which self-reported systemic diseases (hepatitis, asthma, high blood pressure, stroke, liver disease, and diabetes) were associated with a higher caries experience (Johnston and Vieira, 2014).

In Study I, urban/rural clinic location, which is linked with socio-economic status in Norway (Sjolie and Thuen, 2002), was not associated with either DMFT score or DCL-CC. In contrast to our findings, sparsely-populated areas in Norway have been shown to be associated with self-perceived inferior oral health in the adult population when dental service is not free-of-charge (Ekornrud and Jensen, 2010). Our results suggest that free-of-charge PDHS might diminish dental inequality.

6.3 Treatment preferences in Northern Norway

In Study I, 18-year-old subjects with DCL-CC had a higher DMFT score than those without DCL-CC. It is therefore reasonable to assume that they belong to a high caries risk group, and an increased risk of restoration failure has been reported in such groups (Demarco et al., 2012; Opdam et al., 2014). The overall median longevity of composite restorations in permanent
molars is limited. (Mjör et al., 2000; Vähänikkilä et al., 2014). When the time comes to replace deep restorations, the pulp is at risk of exposure. Consequently, the high prevalence of untreated/treated deep carious lesions (23%) found in Study I among 18-year-olds presents a challenge for further treatment. The lack of a uniform treatment preference was demonstrated in Study II, which is in accordance with previous surveys (Oen et al., 2007; Weber et al., 2011; Frisk et al., 2013; Schwendicke et al., 2013b). The absence of a uniform treatment procedure is probably due to the lack of consensus in the literature in this field. The dilemma about whether all caries should be excavated at the first visit is being debated (Ricketts et al., 2013; Schwendicke et al., 2013a). In Study II, when an adult patient presented with a deep carious lesion but no symptoms, only a half of the GDPs preferred TCE, which is less than the proportion reported in previous surveys from the USA, Brazil, and Germany (Oen et al., 2007; Schwendicke et al., 2013b; Weber et al., 2011). GDPs gave IPC as their least preferred treatment for deep carious lesions in Study II, which is in accordance with the above-mentioned surveys. For carious exposure in adults, textbooks and guidelines give pulpectomy as the only treatment method (European Society of Endodontology, 2006; Hasselgren, 2008; Socialstyrelsen, 2011). However, when no symptoms were present, VPT was preferred by more than a half of the GDPs in Study II, which is in line with results from the USA, Sweden, and Germany (Frisk et al., 2013; Oen et al., 2007; Schwendicke et al., 2013b). Although the use of VPT is against the recommendations, its use would be more understandable if MTA were the preferred capping material, but about 75% of the GDPs chose CH (as a slurry and/or paste), although both PP and DPC with CH have been shown to yield low success (< 35%) in a recent randomized trial in which both age and origin of exposure were controlled for simultaneously (Bjørndal et al., 2010).

Is it not clear which evidence GDPs follow, and at which point they assume there is enough evidence to adopt a new treatment method, but it is likely they make their decisions
based on a subjective interpretation, with no universally accepted logical rules (Shahar, 1997). Subjective interpretation can be influenced by scientific knowledge (endodontist, cariologist, clinical pragmatic, etc.), clinical experience, and traditions (Bjørndal and Kidd, 2005; Bjørndal, 2008). In Study II, graduation from a dental school in Norway was associated with the use of conservative treatment options (SWE and IPC) for deep carious lesions, but graduation in Norway and 5 or more years in practice was associated with pulpectomy followed by endodontic treatment in cases of carious exposure accompanied by symptoms. Our finding on the influence of number of years in practice was in line with two other surveys (Weber et al., 2011; Frisk et al., 2013) and might indicate that those with fewer years in practice are avoiding pulpectomy, as root canal treatment might be considered difficult and time consuming. Another possibility is that GDPs with fewer years in practice are more prone to follow recent evidence, but this interpretation is questionable, since CH, not MTA, was still the most preferred material for DPC.

As has been discussed in a previous survey from Brazil, the lack of uniformity in GDPs preferences might be perceived as an “art of dentistry”, but this variability may also have a negative impact on the quality of care (Weber et al., 2011). In Study II, in the absence of carious exposure but the presence of symptoms, four out of 10 GDPs preferred pulpectomy. There is no substantiation for this in any of the dental literature, as the symptoms were intentionally described to refer to reversible pulpitis at most (“sharp transient pain or sensitivity to hot/cold”, (Appendix 1). In such a scenario, SWE or IPC would have an excellent prognosis; even endodontics could not compete (Jordan and Suzuki, 1971; Bjørndal and Thylstrup, 1998; Maltz et al., 2012a). Therefore it is crucial to have guidelines and to follow them. Nevertheless, the present results showed that GDPs’ preference was influenced by other factors, such as patient’s oral health, final restoration, and patient’s age, not just by diagnosis and treatment options, which is in line with an earlier study (Kay and Blinkhorn, 1996).
The goal of Study II was to learn about treatment preferences and routines; however, studies based on data from self-administered questionnaires should be taken with caution. Indeed, in case of uncertainty, heuristic reasoning (intuitive, automatic, implicit processing) plays an important role in treatment preferences (Hicks and Kluemper, 2011).

6.4 MTA and CH as a direct pulp capping material for carious exposures in adults

CH and MTA perform well, almost flawlessly when it comes to children and adolescents, regardless of the state of the root apex (open/closed). Therefore more focus should be placed on the performance of these materials in adult teeth. There are indications that MTA performs better than CH in adult teeth, but so far no comparative prospective study on adults only has been published to show this (Table 2).

In Study III, an imbalance in groups regarding depth of carious lesions assessed from radiographs was detected at baseline. The depth of a carious lesion is one of the most important factors of pulp healing potential (Bjørndal et al., 2014a). However, keeping in mind the two-dimensional presentation of a radiograph, and the fact that in Study III dentists performing treatment were not given instructions as to how to evaluate the radiographic depth of the lesion, this measurement might be subjective and not valid. Also, the depth of the lesion might have more influence when choosing between TCE, SWE, and IPC, in which no exposures are involved, but in Study III each case that was randomized presented with de facto clinical carious exposures, regardless of the depth assessed from radiographs taken prior to the excavation.

The results of Study III favored MTA (survival rate of 80%) over CH (survival rate of 46%). This finding is in accordance with other studies, although they are not fully comparable as previous studies included children and adults with a mixed origin of exposures (Cho et al., 2013; Hilton et al., 2013; Mente et al., 2014). CH may not be perceived anymore as a gold standard. In order to assess whether the success rate of DPC with MTA in adults is high enough to warrant the routine use of these methods, it should be compared with that of pulpectomy.
followed by root canal treatment. The two most recent meta-analyses on orthograde root canal treatment demonstrated an average survival rate of 83%-86% in teeth that were vital or without an apical lesion (Kojima et al., 2004; Ng et al., 2010). It may be argued that for a GDP, DPC is easier to learn and master compared to the root canal treatment, which is relatively complicated. However, a retrospective study demonstrated an almost 90% success rate of pulpectomy followed by root canal treatment 5 years after the procedure performed by GDPs (Alley et al., 2004).

Study III demonstrated a high survival rate in the MTA group, similar to that reported by Hilton and colleagues (2013), but lower than the rate reported in a prospective study by Bogen and colleagues (2008). However, the study by Bogen and colleagues also comprised children and adolescents, with more than half of the patients being younger than 18 years. Thus the higher success rate in their study could have been anticipated, as study by Qudeimat and colleagues (2007) showed a more than 90% success rate in adolescents after PP with both CH and MTA.

After DPC of carious exposures in adults, Study III demonstrated a higher estimated survival rate in the CH group, 46% compared to the 31.8% found in a recent Scandinavian multicenter RCT by Bjørndal and colleagues (2010), despite the fact that Study III had more than double the follow-up time. Patients with deeper carious lesions (3/4 vs. ≥2/3) were recruited in the latter study and a rubber-dam was placed after de facto the carious exposure, which may have a negative impact on their results. Study II indicated that less than 20% of the respondents used rubber-dams at all while treating carious exposures. Although one out of the four clinics recruiting patients for Study III violated protocol by not using a rubber-dam, the survival/failure rate in this clinic was the highest (combining both groups) at 4.4, compared to the average of the rest of the clinics. This calls into question the impact of rubber-dam use in the overall success of DPC, as does a study by de Lourdes Rodrigues Accorinte and colleagues
in which using of rubber-dam showed no difference in pulp healing after DPC with CH in
caries-free molars (de Lourdes Rodrigues Accorinte et al., 2006).

In Study II, symptoms that indicated reversible pulpitis at most, led to a higher rate of
preference for pulpectomy, both in the absence and the presence of carious exposure. This is in
contrast with the literature, as reversible inflamed pulp has the potential to heal (Torabinejad
and Shabahang, 2009; Ricucci et al., 2014b). In Study III, the survival rate of molars with
preoperative symptoms (indicating reversible pulpitis at most) were not statistically
significantly different from the survival rate of molars that did not show any preoperative
symptoms. This finding is in accordance with other studies investigating carious exposures
(Shovelton et al., 1971; Matsuo et al., 1996) and a systematic review investigating deep carious
lesions (Schwendicke et al., 2013c). In contrast, in cases of deep carious lesions without carious
exposure, preoperative pain was associated with lower success rates of TCE and SWE (Bjørndal
et al., 2010). However, there is no clear association between signs and symptoms of pain and
actual pulp status (Mejàre et al., 2012).

In Study III, no significant association was detected between the materials and 1 week
postoperative pain relief or occurrence. This is in line with a Scandinavian RCT comparing
TCE and SWE, which reported no significant difference in postoperative pain relief 1 week
after treatment (Bjørndal et al., 2010). In Study III, there were fewer molars with postoperative
pain after 1 week compared to baseline in both the MTA and CH groups. This is in contrast
with an earlier clinical/histological study, also restricted to adults, in which a statistically
significant increase in symptoms from baseline to 1 week post-procedure was documented after
DPC with CH. But no relation between symptoms and histopathology was found (Fitzgerald
6.5 Future perspectives

Future research perspectives

A high prevalence of 18-year-olds with DCL-CC and who are leaving the free-of-charge PDHS is of concern. Recall dates could only be recorded in a limited number of subjects, and the results from Study I were not in line with the recall strategy described by the Chief Dental Officer in Troms County. The effect of recall routines on the prevalence of caries in Troms County is unknown.

There were indications that the PDHS might eliminate dental inequalities related to socio-economic status. Strong socio-economic variables, such as parental education, occupation, and income, should be included in future studies to reveal the impact of PDHS on dental inequalities.

History of medical problems was associated with a higher DMFT score and extractions due to caries, which is in line with other studies (Alavaikko et al., 2011; Anjomshoaa et al., 2009; Johnston and Vieira, 2014; Little, 2002). To avoid temporal bias, studies with a longitudinal design are needed to study the association between contributory medical history and the prevalence of caries.

Knowledge regarding the prognostic factors for successful VPT other than material is still lacking. Previous studies have demonstrated that people in younger age groups have better healing potential due to more blood flow (Cho et al., 2013; Hørsted et al., 1985; Stanley, 1989), while others did not find any such association (Haskell et al., 1978; Matsuo et al., 1996; Barthel et al., 2000; Al-Hiyasat et al., 2006; Mente et al., 2014). The successful outcome of VPT in carious exposures might also depend on: i) the location of the exposure (Benoist et al., 2012; Cho et al., 2013); ii) the integrity of the cavity restoration (Mjör, 2002); and iii) the extent of the lesion (Maltz et al., 2012a). A prospective study using multivariable Cox regression analysis might answer this question.
**Clinical recommendations**

Targeting caries management to subjects with high DMFT scores in the PDHS might reduce the prevalence of cases with compromised pulps.

Since GDPs in Northern Norway have no uniform strategy for the management of deep carious lesions, often the preferred treatment methods reported were not the best available. Continuous education courses that can inform GDPs about less invasive treatment approaches in cases of carious lesions with reversible pulpitis and could synchronize preferences.

The high success rate of DPC with MTA strengthens the evidence for VPT for carious exposures in adults and might challenge established treatment recommendations.
7. CONCLUDING REMARKS

*Study I* was the first in 2 decades to assess DCL-CC in Northern Norway. At the age of 18 years, subjects registered in the PDHS in Troms County showed a high prevalence of DCL-CC; more than one-fourth had at least one molar affected. Of those with affected molars, almost one in four had untreated deep carious lesions or deep restorations. Of all molars with DCL-CC, more than a quarter had the most severe modalities: root canal obturations and extractions due to caries. One of the most important goals of the PDHS is the early detection and management of carious lesions in order to prevent DCL-CC. Therefore assessing the prevalence of DCL-CC was an innovative angle by which to address the effectiveness of the free-of-charge PDHS. The overall management of carious lesions should be improved and in cases of untreated deep carious lesions and deep restorations, efforts should be made to maintain pulp vitality.

Our survey on the current preferences and clinical routines for the management of deep carious lesions was the first performed in Northern Norway and showed that there was no uniform treatment method for deep carious lesions in mature, permanent, vital teeth. Moreover, treatment methods that are not in accordance with the current literature were preferred: TCE and pulpectomy followed by root canal treatment were preferred in cases of no carious exposure, while in cases of carious exposure the majority of dentists preferred DPC using mainly CH.

MTA performed significantly better, compared with the gold standard of CH, as a pulp capping material in a unique RCT restricted to adults with carious exposures only. In general, the 80% survival rate in the MTA group could be compared with the success rate of pulpectomy followed by root canal treatment. *Study III* is still ongoing, but already provides evidence that suggests a paradigm shift from pulpectomy followed by root canal treatment to VPT for the treatment of carious exposures in adults.
REFERENCES:


66


APPENDIX 1

Questionnaire
Treatment preferences of deep carious lesions in vital, permanent teeth with closed apex.

Please, follow the present guidelines:

- Use blue ballpoint pen
- Mark your answer(s) with an X
- If you want to change your answer, you can shade the box.

Questionnaire

Demographic information

1. Gender
   - Female
   - Male

2. Where have you graduated from
   - Oslo
   - Bergen
   - Tromsø
   - Other university/dental school

3. Present practice
   - Public
   - Private
   - Both

4. Year of practice
   - < 5 years
   - 5 – 10 years
   - ≥ 10 years

5. In which area is your practice
   - Rural
   - Urban

Choice of treatment

6. When deep carious lesion is detected, in which of the following situations do you usually consider pulpectomy and root canal filling (RF) as your primary choice of treatment
7. No symptoms – no subjective complaints or history of pain
Symptoms – sharp transient pain or sensitivity to hot/cold
I usually choose other treatment than RF

If in question 6 in both alternatives you have marked “RF”, please, go to question 10, if not – proceed with question 7

8. In which of the following situations when deep carious lesion is present do you provide total (TOTAL) or partial caries excavation (PARTIAL)

<table>
<thead>
<tr>
<th></th>
<th>TOTAL</th>
<th>PARTIAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>No symptoms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Symptoms</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

If in question 7 in both alternatives you have marked “TOTAL”, please, go to question 10, if not – proceed with question 8

9. If you perform PARTIAL caries removal, how much of soft dentine do you leave
- Just to protect eventual pulp exposure
- Remove totally from the lateral walls, leave at the bottom
- Remove just superficial layer

10. If you perform PARTIAL caries removal, do you include a second visit (stepwise excavation) before placing a permanent restoration
- Yes
- After 6 weeks – 3 months
- After 3 – 6 months
- Longer than 6 months
- No

11. What is your treatment choice of the following situations in case of carious pulp exposure after caries removal
- Direct pulp capping (DPC)
- Partial pulpotomy (PP)
- Pulpectomy and root canal filling (RF)
12. My main reasons for performing the chosen treatment options (questions 5,7,8,9,10) are (mark three most relevant options):

- Easy to operate, familiar
- Brings good results
- Has a biological proof
- Recommended by colleagues
- Recommended in clinical courses
- It is recommended in textbooks
- It is recommended by recently published studies
- Other

13. Which are the main factors your treatment option depends on (mark the three most relevant options)

- Patient’s general health
- Patient’s age
- Patient’s attitude and priority
- Type of tooth (front/premolar/molar)
- Further restoration of the tooth
- Patient’s oral health
- Duration of the total treatment
- Other

**Treatment procedure**

14. Do you use rubber dam for the treatment of deep carious lesion

Yes □

No □

15. Do you use dye solution (caries indicator) during excavation

Yes □

No □

16. What instruments do you use when excavating deep carious lesion

Sharp spoon shaped hand excavator □
Large sharp round bur at a low speed  □
Diamond bur at a low speed  □
Other  □

17. Do you use an antimicrobial agent before a liner or bonding agent is applied
Yes  □
No  □

18. Which material do you usually use as a first layer on the pulpal wall under permanent restoration in the absence of exposure
Calcium hydroxide slurry (powder + water)  □
Calcium hydroxide commercial liner (Dycal, Life etc.)  □
Glass ionomer cement  □
None, directly bonded composite resin  □
Other  □

19. Which material do you usually use as a first layer on the exposed pulp
Calcium hydroxide slurry (powder + water)  □
Calcium hydroxide commercial liner (Dycal Life etc.)  □
Combination of both previously mentioned  □
Zinc oxide eugenol  □
MTA  □
Other  □

20. Are you satisfied with the results of your treatment of deep carious lesions
Yes  □
Partly, I need to improve  □
No, I am not satisfied  □

21. Do you provide follow up after treatment of deep carious lesions
Yes  □
No  □
APPENDIX 2

Invitation letter
Dear Name Surname, we invite you to participate in a survey

Treatment preferences of carious lesions in vital, permanent teeth with closed apexes

The investigation
The present investigation is a part of a PhD-project at The Institute of Clinical Dentistry (IKO) in Tromsø (Norway). The present survey is intended to give relevant information about clinical routines regarding treatment of carious lesions among dentists in Northern Norway. The present investigation is anonymous, no names will be linked to the answers.

Example case
Here you see bitewing and clinical picture of a carious lesion at distal surface of the tooth 14.

You will find enclosed questionnaire asking about preferred treatment methods and materials of cases like this.

Definitions
Total caries excavation: Removal of all infected and affected carious dentine.
Partial caries excavation: Removal of all or part of infected (soft) dentine leaving affected dentine at the deepest part of the cavity.
Direct pulp capping: An exposed pulp is covered with capping material.
Partial pulpotomy: Part of the coronal pulp adjacent to an exposure is removed and the rest part is covered with a capping material.
Pulpectomy: Total removal of vital pulp tissue and root canal filling.

We hope that you are able and willing to participate in the present survey. Please, fill in the questionnaire and put it in prepared stamped envelope, which is enclosed. The results will
increase our knowledge of caries treatment in general practice and give an appropriate background for estimating prognosis of various treatment options used.

If you are willing, you will be personally informed about survey’s results, as soon as they are ready.

Contact us if you are in doubt about something.
Lina Stangvaltaite: 77649132, lina.stangvaltaite@uit.no
Rita Kundzina: 77649118
Harald M Eriksen: 77649103
Eero Kerosuo: 77649128

THANK YOU FOR YOUR COOPERATION!
APPENDIX 3

Written informed consent
Request for participation in the research
"Clinical pulp capping" (Treatment of very deep holes in teeth).

Background and purpose
This is a question for you to participate in a dental examination on the treatment of very deep holes in the teeth. Such holes (caries attack) that reach into the nerve of the tooth can be painful and is a treatment challenge. One is presented with options to cover the wound with a special type of insulating cement before making a normal filling or root canal treatment the tooth. The first option is easy and affordable, while a root canal can be technically demanding and expensive. It is therefore important to find good and safe guidelines for selecting the best and safest option in such situations.

What does the study?
The method involves sårdekning of an exposed nerve in the tooth has been known and taught in more than 50 years. Materials and criteria have varied over time and the results have been uncertain. Over the past few years has developed a new material (Mineral trioxide Aggregate, MTA), which shows promising properties. The material is tested in experimental models and in normal clinic without having found adverse side effects. What is lacking, however, controlled clinical trials comparing the results of treatment with a traditional cement with the new material. MTA is as the name says a mineral oxides without medical additives.
You are invited to participate in a survey in which a process suitable teeth either traditionally or with the new material for a random distribution. The teeth will be followed up with examinations after 6, 12, 24 and 36 months by an experienced dentist who does not know which of the two treatment options that are used. If you experience pain or discomfort with the treatment during the study period, there will of course be taken care of.

Advantages and disadvantages
The advantages for you as a participant is competent treatment for well gjennomarbeidete guidelines, close monitoring of the outcome of treatment and rapid access to treatment for any complications. As responsible for the study, we expect no disadvantages over the elapsed time for annual inspections.

What happens to your information (privacy)?
All personal information about you especially related to the survey will be used only in this context and will be deleted at the end of the study. Only authorized personnel involved in the project that has access to the name lists and other information related to the study. It will not be possible to identify the results of the study when they are published, but you will be informed of the results.

Right of access
It recorded only regular journal information in connection with the study and the right of access to follow patients' right to access their own records.

Voluntary participation
It is voluntary to participate in the study. If you do not want to join the tooth to be treated by the commonly used guidelines at the clinic. If you wish to participate in the draw you consent to the statement on the last page. If you now agree to participate, you can later withdraw your consent without affecting your other treatment. The study is in accordance with normal, necessary dental treatment and will therefore not be given special compensation for
participating.

Economy
The study is funded by research grants available from the Department of Clinical Dentistry, University of Tromsø and the dental health resource center for northern Norway. There will also be applied for research funding from independent external research funds. There are no ties to commercial companies.

Insurance
In that study represents the normal, necessary dental treatment, the participants are insured through existing patient and insurance responsibilities.

Further information
Detailed information can be found in the project description that is available to participants if desired. 1. Professor Rita Kundzina
Main Responsible
E-mail: rita.kundzina @ uit.no, phone: 77 64 91 18

Consent Statement:
I have received and read the written information about the study, "Clinical pulp capping" and is willing to participate in the survey.
Date: __________
Signature: ________________________
Block Letters: ________________________
APPENDIX 4

Data application sheet
Baseline

1. _______    Patient’s OPUS number
2. _________    Patient’s birthday
3. ____________________    Clinic
4. _________    Date of capping procedure
5. ____________________    Operator
6. _______    Tooth number
7. ______    Cavity type
   - 1=MO   2=DO   3=MOD
8. _______    Pre-operative pain history
   - 1=No   2=Yes, but indicating not more severe condition than reversible pulpitis
9. _______    Medical status at baseline
   - 1=Non-contributory
   - 2=Use of antibiotics during the last year, but not during the last 3 weeks
10. _______    Caries depth at baseline
    - 1=Reaching inner 1/3, but not deeper
    - 2=Clearly beyound the inner 1/3 limit, but not into pulp
    - 3=Into the pulp
11. _______    Periapical status at baseline
    - 1=Normal, apex closed
12. _______    Periodontal status
    - 1=Normal
    - 2=Deepened pocket but NOT > 4 mm
13. _______    Vitality at baseline
    - 1=Response to cold or EPT
14. _______    Written consent obtained
    - 1=Yes, signed

15. _______    Pulpal exposure
    - 1=Yes
    - 2=No
16. _______    Hemostasis
    - 1=Yes
- 2=No
17. |   | Clinic allocation number (1-20)
18. |   | Allocated material
    - 1=Dycal
    - 2=MTA ProRoot grey

Second visit (1 week)
19. |   |   |   |   |   |   | Date at final restoration
20. |   | Pain during the first week and/or at second visit (1 week)
    - 1=No
    - 2=Yes, but during the 3 first days only and not indicating more severe than reversible pulpitis
    - 3=Yes, occasionally during the entire week, but not at present. But not indicating more severe than reversible pulpitis.
    - 4=Yes, pain at present, but not indicating more severe than reversible pulpitis
    - 5=Yes, severe pain earlier or at present indicating irreversible pulpitis
6 months

1. [ ] [ ] [ ] [ ] [ ] [ ] [ ] Patient’s OPUS number

21. [ ] [ ] [ ] [ ] [ ] [ ] [ ] Date of 6 months examination

22. [ ] Pain at 6 months or during the followed period
   - 1=No
   - 2=Yes, but not indicating more severe than reversible pulpitis
   - 3=Yes, indicating irreversible pulpitis or more severe

23. [ ] Vitality at 6 months
   - 1=Response to cold or EPT
   - 2=Lingering
   - 3=No response on either method

24. [ ] Periapical status at 6 months
   - 1=No lesion
   - 2=Widening PDL
   - 3=Lesion
12 months

1. Patient’s OPUS number

25. Date of 12 months examination

26. Pain at 12 months or during the followed period
   - 1=No
   - 2=Yes, but not indicating more severe than reversible pulpitis
   - 3=Yes, indicating irreversible pulpitis or more severe

27. Vitality at 12 months
   - 1=Response to cold or EPT
   - 2=Lingering
   - 3=No response on either method

28. Periapical status at 12 months
   - 1=No lesion
     - 2=Widening PDL
     - 3=Lesion
24 months

1.  |_|_|_|_|_|_| Patient’s OPUS number

29.  |_|_|.|_|_|.|_|_|_|_| Date of 24 months examination

30.  |_| Pain at 24 months or during the followed period
     - 1=No
     - 2=Yes, but not indicating more severe than reversible pulpitis
     - 3=Yes, indicating irreversible pulpitis or more severe

31.  |_| Vitality at 24 months
     - 1=Response to cold or EPT
     - 2=Lingering
     - 3=No response on either method

32.  |_| Periapical status at 24 months
     - 1=No lesion
     - 2=Widening PDL
     - 3=Lesion
36 months

1. [ ] [ ] [ ] [ ] [ ] Patient’s OPUS number

33. [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] Date of 36 months examination

34. [ ] Pain at 36 months or during the followed period
   - 1=No
   - 2=Yes, but not indicating more severe than reversible pulpitis
   - 3=Yes, indicating irreversible pulpitis or more severe

35. [ ] Vitality at 36 months
   - 1=Response to cold or EPT
   - 2=Lingering
   - 3=No response on either method

36. [ ] Periapical status at 36 months
   - 1=No lesion
   - 2=Widening PDL
   - 3=Lesion

37. [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] Date of exclusion